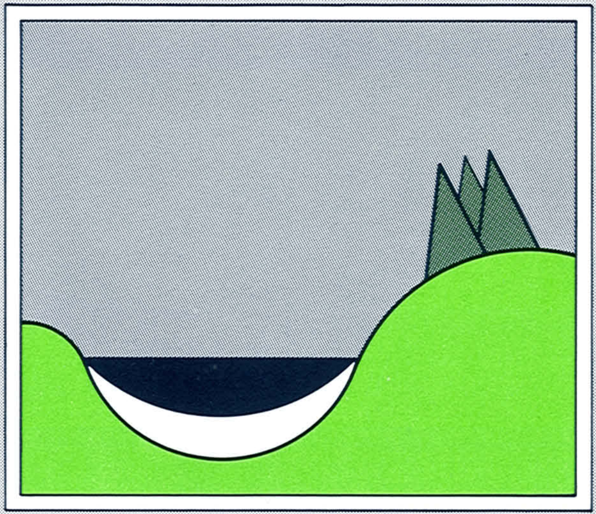
Earth Sciences Report 82-1

MARL Resources of Alberta



by D.E. Macdonald

Alberta Geological Survey

Alberta Research Council

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ABSTRACT

Freshwater marl and tufa deposits in Alberta were surveyed and evaluated as possible sources of calcium carbonate for use in treating acidic agricultural soils. Fieldwork was concentrated in the Peace River-Grande Prairie and central regions of Alberta. The total marl and tufa resources of these two areas, based on this study, are estimated to be 10 million m^3. Few deposits are present in the Peace River-Grande Prairie area and only three of these exceed 50 000 m^3 in size. Deposits in central Alberta are confined to two areas: west of the 5th meridian, and north of latitude 53°30′. Tufa deposits are concentrated in the western region and are numerous; few, however, exceed 10 000 m^3 in volume. Nine marl deposits in central Alberta exceed 50 000 m^3, five of which exceed one-half million m^3 of marl each.

Acid soils in the Grande Prairie, western, and north-central regions of Alberta could be ameliorated utilizing local marl deposits; however, the treatment of acid soils in the east-central part of the province would require transporting the material a distance greater than 160 km.

Most of the calcareous deposits examined contain greater than 50 percent Calcium Carbonate Equivalence (C.C.E.), which is the quality cut off used in this report to define marl. The marl is mainly fossiliferous micrite with calcareous algae (*Characeae*) present in various amounts. Contaminants include organic detritus and quartz. Clay minerals generally constitute less than 5 weight percent of the marl.

Tufa usually contains greater than 80 percent C.C.E., is well indurated, and consists of micrite and coarser calcite.

The formation of the marl and tufa deposits requires a source of calcium carbonate within the glacial drift or bedrock. The deposition process is manifest through leaching of this carbonate by percolating acidic groundwater, transportation of calcium bicarbonate ions in an aquifer, discharge at the surface, and precipitation of calcium carbonate due to the removal of CO_2 from the water. Ideal conditions for marl deposition include a cool, moderately humid climate with a spruce forest vegetation. Under these conditions, a maximum amount of leaching occurs. Presence of high topographic relief to promote groundwater flow through short, local groundwater systems favors marl deposition. Marl generally forms at ponded discharge sites and tufa forms at well-drained sites.

Eight major classes of deposits, based on mode of formation and geological and hydrogeological setting, have been established.

1. *Hillside-spring* deposits are tufa and marls deposited where springs discharge on a hillside.

2. *Spring mound* marl deposits are centered around springs discharging onto flat glaciolacustrine terrains.

3. *Spring fed lake* marl deposits occur in lakes currently or at one time fed by springs discharging from bedrock.

4. *Shoreline fringe* marl deposits occur as belts along shorelines of large lakes.

5. *Abandoned channel* marl deposits are present in Recent ox-bow lakes or postglacial abandoned channels; none are currently precipitating marl.

6. *Seepage ponded* marl deposits occur in ponds, swamps, and small lakes that are fed by short, local groundwater systems confined to glacial drift.

7. *Hillside-seepage* marl deposits form in areas of diffuse groundwater seepage along hillsides.

8. *Miscellaneous* includes preglacial marl beds, deposits in Recent back swamps along streams, alkali flat deposits and calcareous sediments of Recent age. None of these deposits are of commercial potential.

PART I

BACKGROUND INFORMATION

INTRODUCTION

PURPOSE AND SCOPE

Much of Alberta's agricultural soil has become acidic (Fig. 1) with a resultant decrease in productivity. Soil acidity results from several processes including: continual crop production, overuse of nitrogen fertilizers, and leaching of calcium and magnesium ions by rainwater. The natural leaching of soils is enhanced by acidic rainfalls, resulting from sulfur dioxide air pollution.

The effect of soil acidity on plant growth is largely indirect. Most plants can thrive in all but extremely acidic or basic environments, all other factors being equal (Allaway, 1957). Soil pH is, however, critical in controlling the availability of certain plant nutrients. Metals such as aluminum, iron, manganese, copper, and zinc are sufficiently soluble in acidic environments to become toxic to plants. Increased pH, to more neutral conditions, causes these ions to form inert oxides and hydroxides, eliminating toxicity. If the pH is increased to highly basic or alkaline conditions, the solubility of these metallic ions becomes so low that they are unavailable to plants as nutrients, and productivity drops. Bacteria and micro-organisms, which help make nitrogen, phosphorus, and sulfur more readily available to plants, seem to thrive best in neutral pH environments.

The most common treatment for acidic soils has been to apply crushed limestone, crushed shells, tufa, or marl; the type of material applied generally depends on cost and local availability. "Liming," or applying these highly calcareous materials to the soil, has the effect of increasing soil pH by replacing H^+ ions with Ca^{+2} ions on clays and organic colloids. The amount of calcareous material needed to neutralize a given soil depends on climate, soil, texture, and the desired level of pH to which a soil must be raised. Table 1 (Allaway, 1957) shows the amount of liming material needed for various soils and climatic conditions.

Recognizing the problem of acidic soils in Alberta (Fig. 1), Alberta Agriculture commissioned the Alberta Research Council to explore for and evaluate marl and tufa deposits as possible sources of agricultural lime. The objective was to locate marl

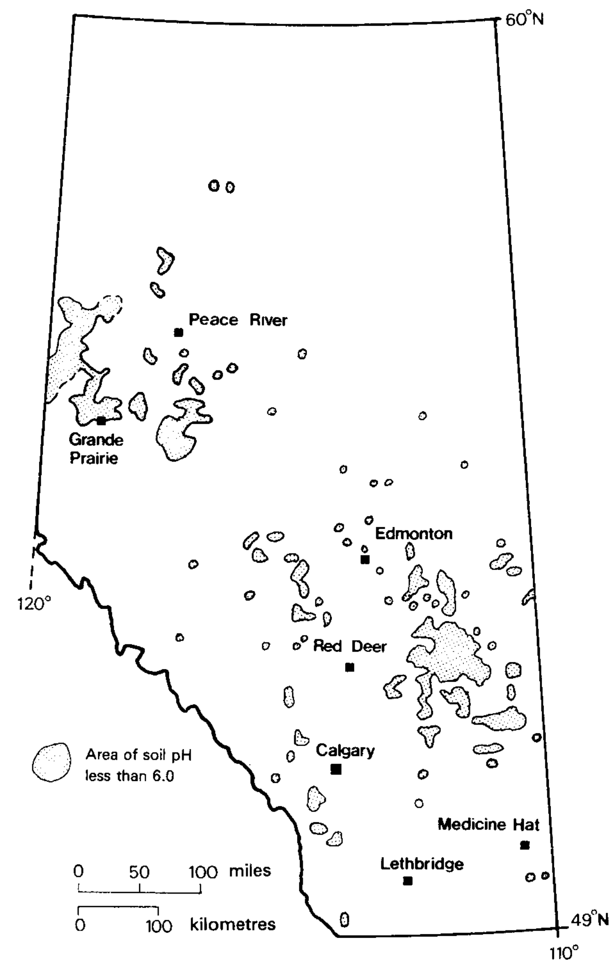


FIGURE 1. Acid soil areas of Alberta

or tufa deposits near the areas of acid soils, which could be exploited economically for soil liming. The only alternative source of agricultural lime at present is limestone from quarries in the Rocky Mountains. Limestone from the mountains is expensive because of high crushing and shipping costs, and present production is largely committed to the cement industry.

This study, conducted from 1976 to 1978, was concentrated in and around the two principal acid soil regions of Alberta, the Peace River-Grande Prairie area and a large region in east-central Alberta. Figure 2 shows the areas explored in detail during this program and those examined on a reconnaissance basis.

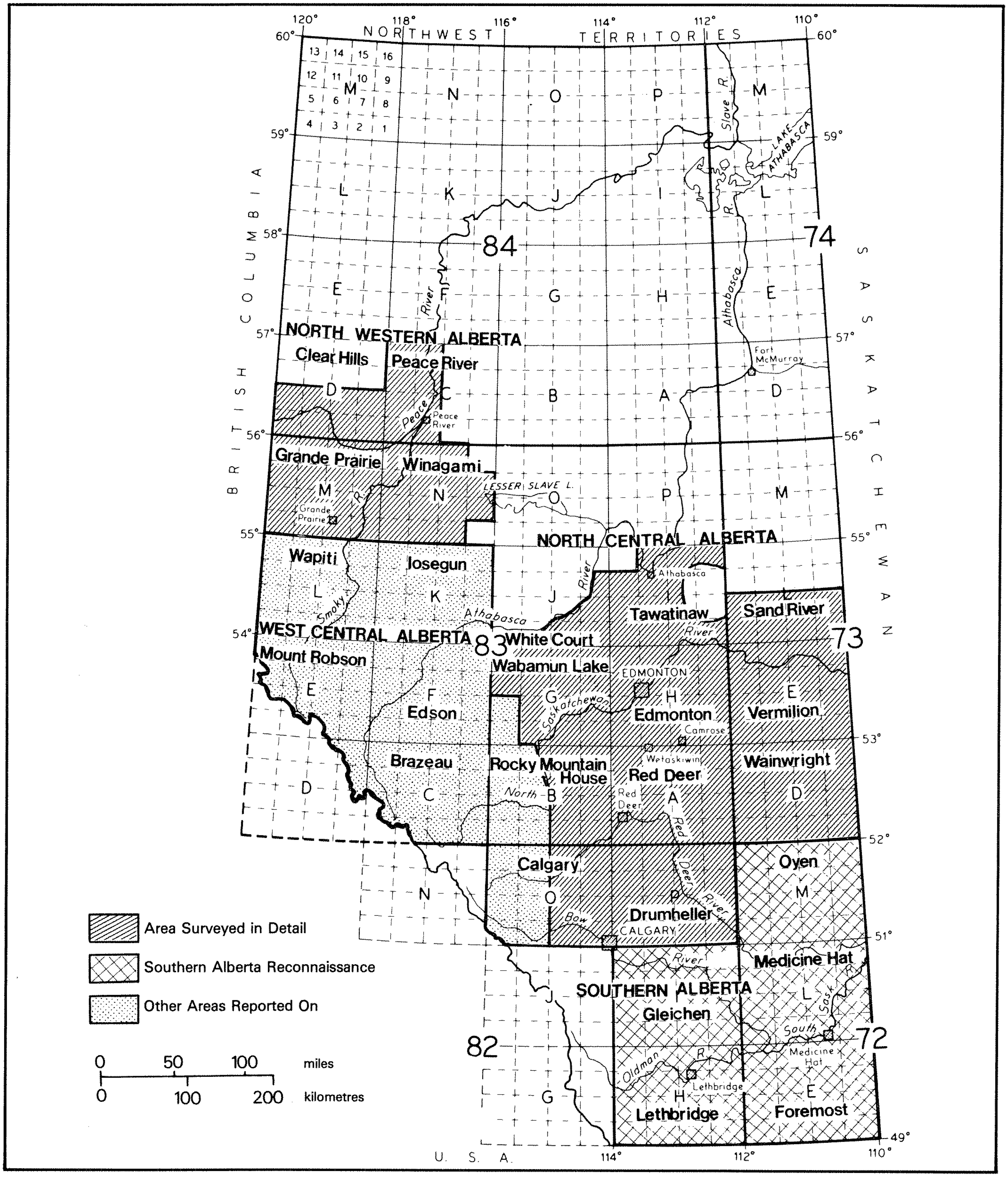


FIGURE 2: Study area and the National Topographic System (N.T.S.) of maps in Alberta

PREVIOUS INVESTIGATIONS

Interest in the marl and tufa deposits of Alberta, and North America in general, was highest from the turn of the century to about World War II. Before this study, however, investigations were confined to a few small areas of the province. Holter (1974a, 1974b) investigated individual deposits in the Peace River and Hand Hills areas and various individuals and companies worked on a few other deposits. Wherever possible, these results are included in this report.

METHOD OF STUDY

This program began with the study of known marl deposits, to develop a model to guide later exploration. These deposits showed a wide variation in depositional environments. General conditions required for marl deposition were found to be: (1) groundwater discharge, particularly water rich in Ca^{+2} and HCO_3^- ions; (2) regions with strong topographic relief; and (3) discharge areas adjacent to highly permeable, carbonate rich, recharge areas. Areas meeting these conditions were explored.

Additional information, which helped guide exploration, was obtained from aerial photographs, existing geological reports, and discussions with local residents and scientists who had worked in the study area. Visual sightings were made during traverses on foot or by truck, and observations from fixed-wing aircraft were also used to locate potential deposits in the Peace River area. Exploration "targets" and deposits were plotted on 1:50 000 scale National Topographic System (N.T.S.) maps.

Testholes were drilled at selected sites using a hand-operated coring device. All intervals sampled were tested in the field with weak (10 percent) HCl

TABLE 1.
Approximate amounts of finely ground limestone needed to raise the pH of a 7-inch layer of soil as indicated [1, 5]

Soil regions and textural classes	Limestone requirements: From pH 3.5 to pH 4.5 Tons per acre	From pH 4.5 to pH 5.5 Tons per acre	From pH 5.5 to pH 6.5 Tons per acre
Soils of warm-temperate and tropical regions:[2]			
Sandy and loamy sand	0.3	0.3	0.4
Sandy loam	....	.5	.7
Loam	....	.8	1.0
Silt loam	....	1.2	1.4
Clay loam	....	1.5	2.0
Muck[3]	2.5	3.3	3.8
Soils of cool-temperate and temperate regions:[4]			
Sand and loamy sand	.4	.5	.6
Sandy loam	....	.8	1.3
Loam	....	1.2	1.7
Silt loam	....	1.5	2.0
Clay loam	....	1.9	2.3
Muck[3]	2.9	3.8	4.3

[1]All limestone goes through a 2-mm mesh screen and at least ½ through a 0.15-mm mesh screen. With coarser materials, applications need to be greater. For burned lime about ½ the amounts given are used; for hydrated lime about ¾.
[2]Red-Yellow Podzol, Red Latosol, etc.
[3]The suggestions for muck soils are for those essentially free of sand and clay. For those containing much sand or clay the amounts should be reduced to values midway between those given for muck and the corresponding class of mineral soil. If the mineral soils are unusually low in organic matter, the recommendations should be reduced about 25 percent; if unusually high, increased by about 25 percent, or even more.
[4]Podzol, Gray-Brown Podzol, Brown Forest, Brown Podzol, etc.
[5]Source: (Allaway, 1957)

acid to obtain an approximate idea of calcium carbonate content. In general, intervals that showed a strong reaction to the acid were sampled and analyzed in the laboratory for Calcium Carbonate Equivalence (C.C.E.)[1]. An attempt was made to delineate the extent and quality of deposits at sites that had a high calcium carbonate content.

LABORATORY PROCEDURES

All samples collected were analyzed for C.C.E. using a back titration method as described by Chapman and Pratt (1961).

Marl from some of the more promising deposits was subjected to chemical analysis, as well as examined using X-ray fluorescence and X-ray diffraction techniques. These analyses were run on composite samples formed from individual samples collected at one or two representative testholes at a given deposit. The chemical analyses were used to estimate the amount of detrital non-carbonate and organic material present (Fig. 3). The non-carbonate component was derived by adding all the mineral-forming chemical components excluding CaO, Loss on Ignition (L.O.I.), CO_2, and H_2O. The organic content was estimated from the difference between the L.O.I. and CO_2 values, which was thought to be a reliable estimate to within 1 or 2 percent. Each composite sample underwent X-ray diffraction (XRD) determinations twice. A bulk or whole rock XRD determination generally revealed all minerals that are more abundant than about 3 percent. A centrifuged and concentrated XRD determination showed those minerals less than 3 percent in abundance and in the clay-size fraction ($- 2\mu m$).

Particle-size analysis (Krumbein and Pettijohn, 1938) was performed on surface grab samples collected from four of the larger marl deposits in the province. Tufa deposits were not analyzed for grain size distribution because in any given deposit there was too much variability in grain size to obtain a representative sample. A selected group of grab samples were examined using a scanning electron microscope, and binocular and petrographic microscopes.

[1] Calcium Carbonate Equivalence (C.C.E.), used throughout this report, is a measure of a substance's ability to neutralize acid.

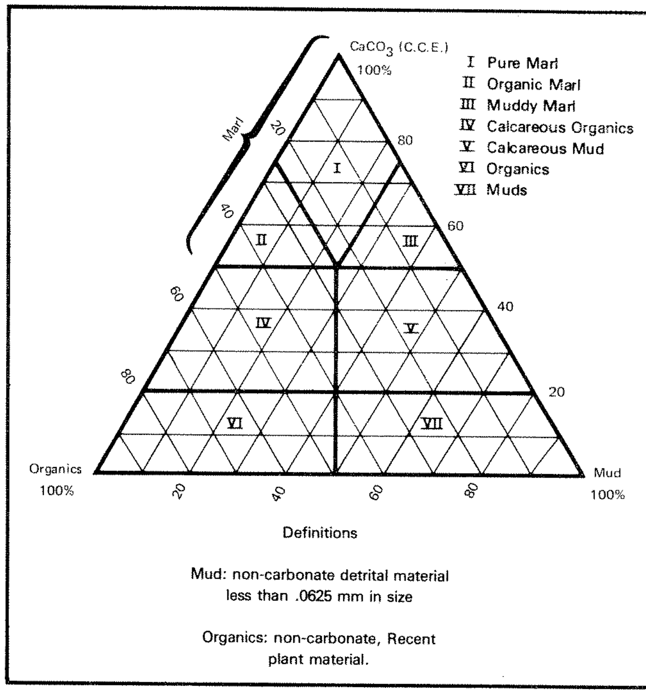


FIGURE 3. Classification of recent terrestrial sediments

MARLS, TUFAS, AND CALCAREOUS MATERIALS

CALCIUM CARBONATE DEFINITIONS

There is no widely accepted nomenclature defining marl. Pettijohn (1957) defines marl as a "semifriable mixture of clay materials and lime carbonate." Barth, Correns and Estola (1939, in Pettijohn, 1957) suggest that marl be restricted to rock containing 35 to 65 percent carbonate with a complementary amount of clay. Of the calcareous sediments analyzed in this study, the C.C.E. values range from 20 to 99.5 percent, but for samples containing greater than 65 percent C.C.E. the major non-carbonate mineral is seldom clay. All calcareous sediments examined are made up of variable proportions of calcium carbonate, insoluble detritus, and non-carbonate plant material.

In this report, "marl" is defined as a freshwater sediment that contains 50 percent C.C.E. or greater, is soft and friable, consisting of a mixture of silt-sized or smaller particles and larger shell fragments. Sediments containing 20 to 49 percent C.C.E. are termed calcareous sediments. Figure 3 contains definitions of the terms used in this report.

There is good agreement among workers as to the definition of "tufa." Pettijohn (1957) defines it as ". . . a spongy, porous rock which forms a thin surficial deposit about springs and seeps and exceptionally in rivers. The calcium carbonate is commonly observed to have precipitated upon leaves, mosses, and stems, is usually not an extensive deposit and is Recent to Quaternary in age." This definition applies throughout this report. Deposits of intermixed tufa and marl were found in some places.

Travertine, a dense-banded form of calcium carbonate found around springs and caverns, was found at some tufa deposits in Alberta.

CALCIUM CARBONATE CHEMISTRY

The precipitation and solution of calcium carbonate is controlled by the equilibrium reaction:

$$CaCO_3 + H_2CO_3 \rightleftharpoons Ca^{+2} + 2HCO_3^-$$
$$\upharpoonleft\downharpoonright$$
$$H_2O + CO_2.$$

Various factors influence which direction the reaction will proceed:

1. The partial pressure of carbon dioxide is one of the main controlling factors. An increase in gas pressure will force calcium carbonate to dissolve whereas a decrease in gas pressure induces carbonate precipitation.

2. Low values of pH (acidic conditions) produce a forward reaction and the converse is true.

3. Temperature also effects the reaction: increased temperature causes a decrease in the solubility of CO_2 and hence a decrease in the solubility of calcium carbonate.

4. The presence of other ions in solution, such as phosphate, tends to cause calcium carbonate to remain in solution (Roddick, 1970).

THEORIES OF MARL AND TUFA FORMATION

Precipitation by Freshwater Molluscs

Mollusc remains are nearly always found in marl suggesting that their presence may contribute to the formation of marl. Molluscs are known (Roddick, 1970) to be able to create a micro-environment around themselves that is saturated in Ca^{+2} and Mg^{+2} ions in order to precipitate a $CaCO_3$ shell. Many calcareous sediments in Alberta may have derived the bulk of their $CaCO_3$ content from freshwater molluscs, as mollusc shells, crushed and preserved, are often the only expression of $CaCO_3$ identifiable in these sediments.

Physico-chemical Precipitation

This theory (Thiel, 1930) advocates that rainwater percolating through calcareous drift and/or outwash takes Ca^{+2} and HCO_3^- ions into solution and groundwater then transports them to a discharge point. When the groundwater is discharged into a lake, pond, or spring, a sudden loss of CO_2 combined with increased temperatures brings about precipitation of calcium carbonate in order to maintain equilibrium. The groundwater must be saturated, or super-saturated, with calcium carbonate for this process to be possible. This process is thought to be responsible for many of the marl and tufa deposits found in Alberta.

Precipitation by Thermal Stratification

Some deposits of marl are thought to form in the epilimnion of lakes, that zone of warm, well-aerated water immediately below the surface (Roddick, 1970). This zone promotes the growth of algae and other organisms that by their metabolism decrease the CO_2 and increase the O_2 content of the water, both of which contribute to the precipitation of marl. Also, any cold groundwater reaching the epilimnion is warmed and agitated, which tends to drive off CO_2 dissolved in it, causing precipitation of marl.

Marl accumulates in a restricted peripheral girdle around the lake basin by lying between the thermocline (base of the epilimnion) and the water table (Roddick, 1970). Marl that passes through the thermocline is redissolved in the colder acidic water. Most marl is deposited during the summer when the epilimnion is best developed. Marl deposits are generally not found in larger lakes as mixing of the water by wind action prevents the formation of the epilimnion.

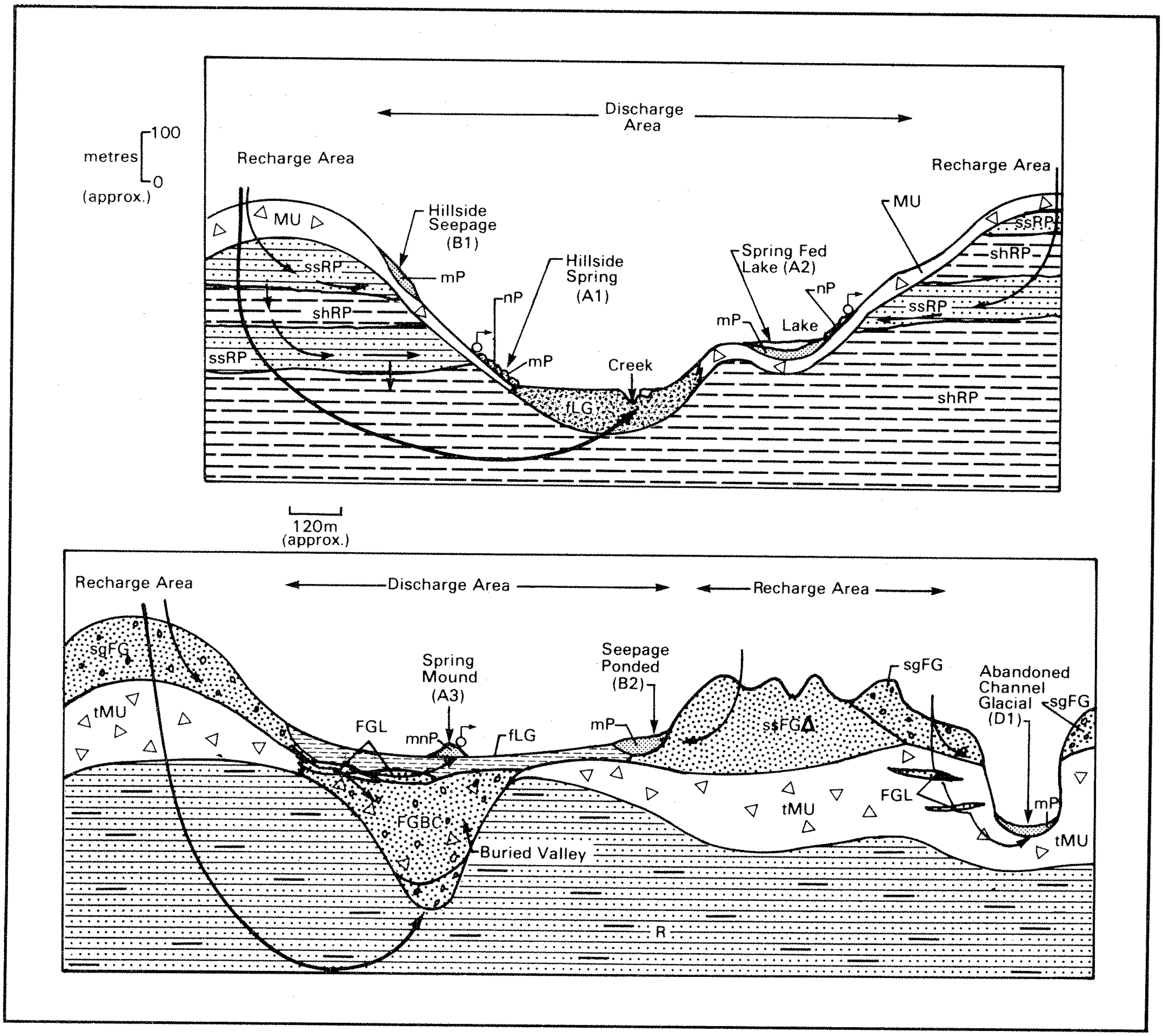


FIGURE 4. Geological settings of some classes of deposits in Alberta (see Appendix 10 for legend)

Precipitation by Plants

The respiration of various plants has long been known to cause precipitation of calcium carbonate because they use CO_2 from the water. Species of one family of green algae (the *Characeae*) are often cited (Davis, 1900; Roddick, 1970) as the main contributor to large marl deposits. Blue-green algae are also thought by some to be instrumental in precipitating calcium carbonate (Kupsch, 1956).

ALBERTA MARL AND TUFA

ORIGINS

Marl deposits in Alberta have several common features: (1) association with present or former groundwater discharge areas; (2) location in topographically low and poorly drained areas; (3) adjacent to highly permeable recharge areas; (4) association with groundwater having a high concentration of Ca^{+2} and HCO_3 ions. Tufa deposits have the following general properties: (1) they occur at obvious groundwater discharge sites; (2) they are more or less independent of topography; (3) they are deposited by flow from aquifers primarily in the Tertiary-Cretaceous Paskapoo Formation; and (4) the groundwaters are always high in calcium and bicarbonate ions.

The origin of most marl and tufa deposits examined in Alberta is seen to be fundamentally dependent on the presence of an original "source carbonate" within the bedrock or drift (as described by Thiel, 1930). As groundwater moves downward, carbonic acids leach the "source carbonate" and the groundwater becomes rich in Ca^{+2} and HCO_3 ions. Highly permeable recharge areas enhance this process. A cool, moderately humid climate with a spruce forest vegetation cover probably produces the maximum amount of carbonic acids for leaching. Several factors determine whether marl and/or tufa will form at the surface once the groundwater is discharged;

TABLE 2.
Characteristics and Classification of Freshwater Calcium Carbonate Deposits

Class		Characteristics				
		Type of $CaCO_3$	Size of Deposit*	Quality of Material*	Source of Ca^{+2} HCO_3^- Water	Source Aquifer
A-1	Hillside Spring	Marl and Tufa	Small	Good	Groundwater Spring	Bedrock
A-2	Spring Fed Lake	Marl, minor Tufa	Large	Good	Groundwater Spring	Bedrock
A-3	Spring Mound	Tufa and Marl	Small to Intermediate	Good	Groundwater Spring	Drift
B-1	Hillside Seepage	Marl	Small to Medium	Good	Groundwater Seepages	Bedrock
B-2	Seepage Ponded	Marl	Intermediate to Large	Fair to Good	Groundwater Seepages	Permeable Surficial Sediments
C.	Shoreline Fringe	Marl	Small to Intermediate	Poor to Good	Groundwater?	Surficial Sediments or Bedrock
D-1	Abandoned Channel Glacial	Marl Tufa	Small to Intermediate	Poor to Good	Groundwater Discharge	Surficial Sediments and/or Drift
D-2	Abandoned Channel Oxbow Lake	Marl Tufa	Small to Large	Poor to Good	Groundwater or Surface Water	Surficial Sediments and/or Drift
E.	Floodplain	Marl	Small	Poor	Surface Water	-
F.	Recent Lacustrine Calcareous Sediments	Calcareous Sediments	Variable	Calcareous to Poor	Groundwater	Surficial Sediments
G.	Alkali Flats	Calcareous Sediments	Variable	Calcareous	Groundwater	Variable
H.	Preglacial	Calcareous Sediments	Trace to Small	Calcareous to Poor	?	?

*See Table 9 for definition of terms.

most relate to the removal of CO_2 gas from the water. The removal of CO_2 by surface aeration, algal photosynthetic activity, increased surface temperature, and the thermal stratification, all cause $CaCO_3$ to precipitate.

The details of these factors and others that influence this process are discussed in Appendix 1. Appendix 2 deals with the distribution and evolution of marl deposits in general.

Depositional Site	Mechanism of Precipitation	Air Photo Expression
Hillside	Physico-chemical (temperature, aeration)	Fair with Experience
Lake Basin	Physico-chemical (thermal stratification, Algae)	Very Good
Flat Terrains	Physico-chemical	Poor
Hillside	Physico-chemical	Very Poor
Lakes or Ponds	Physico-chemical and/or Biological (Algae)	Very Good
Shallows of Large Lakes	Physico-chemical (thermal stratification, Algae)	Nil to Fair
Glacial Channel Lakes and Ponds	Physico-chemical Algae	Poor
Recent Oxbow Lakes	Physio-chemical Algae	Poor
Floodplains	?	Nil
Lake Basins	?	Nil
Lakes and Ponds	Physico-chemical (evaporation)	Fair
Lakes	?	Nil

CLASSIFICATION OF DEPOSITS

In this report, marl and tufa deposits are grouped into twelve classes based on their setting and to a certain degree on variations in mode of genesis (Table 2, Fig. 4).

A-1. *Hillside spring:* Marl and tufa are commonly deposited at hillside springs present at contacts between drift and bedrock or between sandstones and shales (Fig. 4). These deposits form in areas underlain by the Tertiary-Cretaceous Paskapoo Formation, which contain units of permeable calcite-cemented sandstone that form good aquifers and provide carbonate-rich groundwater.

The spring opening is usually free of calcium carbonate deposits. Tufa deposits are present some distance downslope, commonly as terraces. Downslope from the area of tufa deposition, mixed marl-tufa deposits are common in an open meadow setting. Calcium carbonate content gradually decreases farther downslope and marl eventually grades into organic sediments. Surface aeration and increased temperature upon discharge of carbonate-rich groundwaters are believed to be the key factors in precipitation.

Hillside spring deposits are generally small[1], but contain good[1]-quality calcium carbonate. They are generally not economically attractive.

A-2. *Spring-fed lake* deposits are similar to the A-1 class except that the spring discharge flows a short distance to enter a lake or pond (Fig. 4). Tufa accumulates on land near the spring and marl is deposited in the lake. Thermal stratification and physico-chemical processes are likely more important than algal ones in the precipitation of $CaCO_3$. The deposits are often of good[1] quality and of large[1] size and may contain *Chara* sp. remains.

[1] See Table 9 for definition of quantity and quality terms.

Aerial photographic expression is usually good. The lake bottoms are typically white (Plate 1). The large size and high C.C.E. content of these deposits makes them economically attractive.

A-3. *Spring mound* is a mound-shaped deposit up to 3 m high at the site of a spring discharging on flat glaciolacustrine terrain (Fig. 4). Spring waters can usually be traced to buried drift aquifers. The deposits are mixed marl-tufa and are confined to the immediate region around the spring. Deposition is probably the result of physicochemical processes. Deposits are small to intermediate in size, and are of good quality.

B-1. *Hillside seepage* forms where diffuse groundwater discharges from shallow bedrock aquifers along hillsides (Fig. 4 and Plate 2). The deposits are usually covered with vegetation and consist of good quality, nontufaceous marl. The deposits are generally small to medium in size, water saturated, and are thought to be produced by physicochemical processes.

B-2. *Seepage-ponded* deposits are readily identifiable in the field as ponds with white or yellow bottoms and are also readily identifiable on aerial photos (Plates 3 and 4). Deposits are found in areas of hummocky terrain that are characterized by short ground-

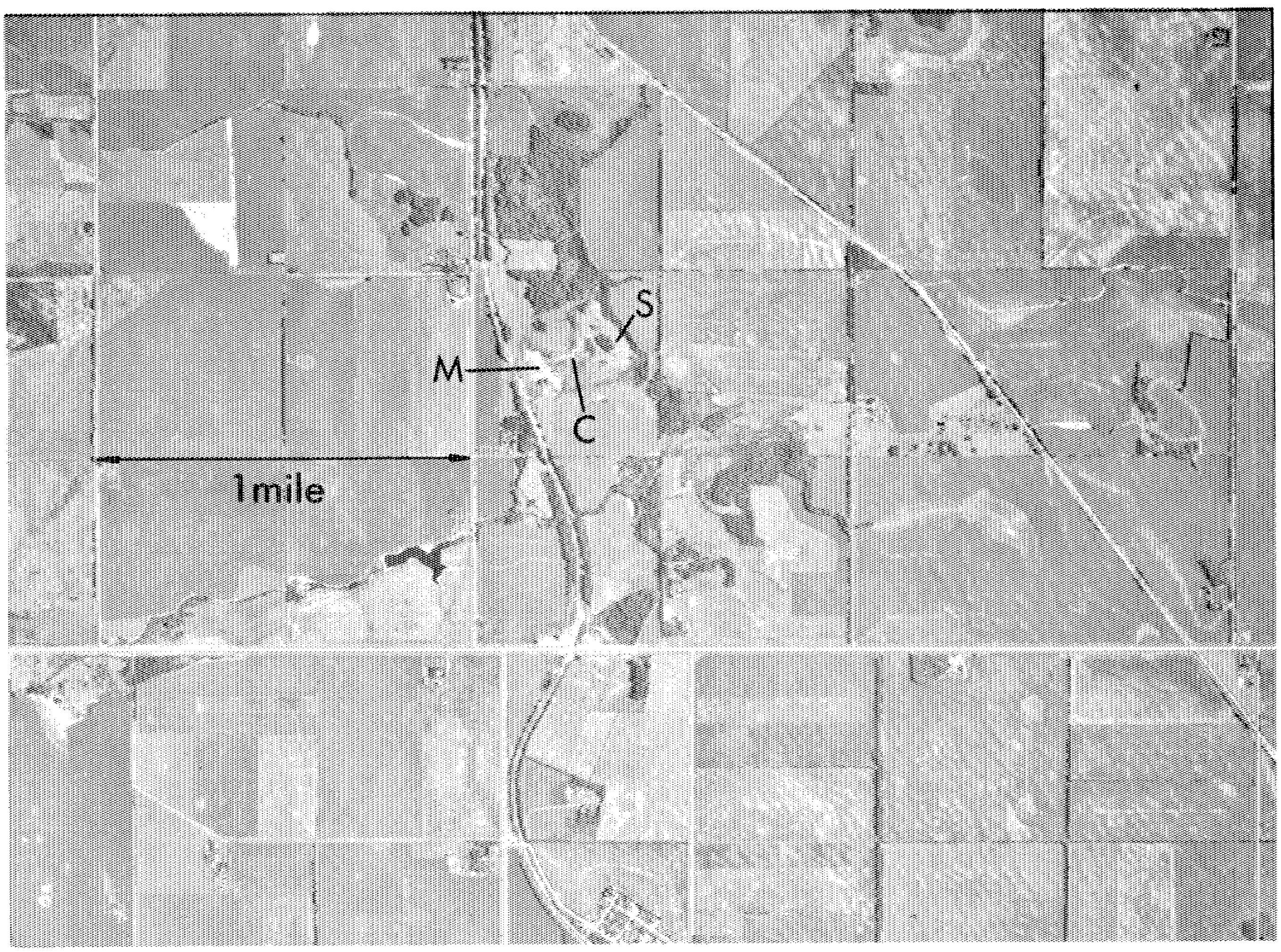


PLATE 1. Benalto deposit - Spring fed lake type (A-2), lake has been drained by creek (C). S - spring, M - marl exposed at or near surface.

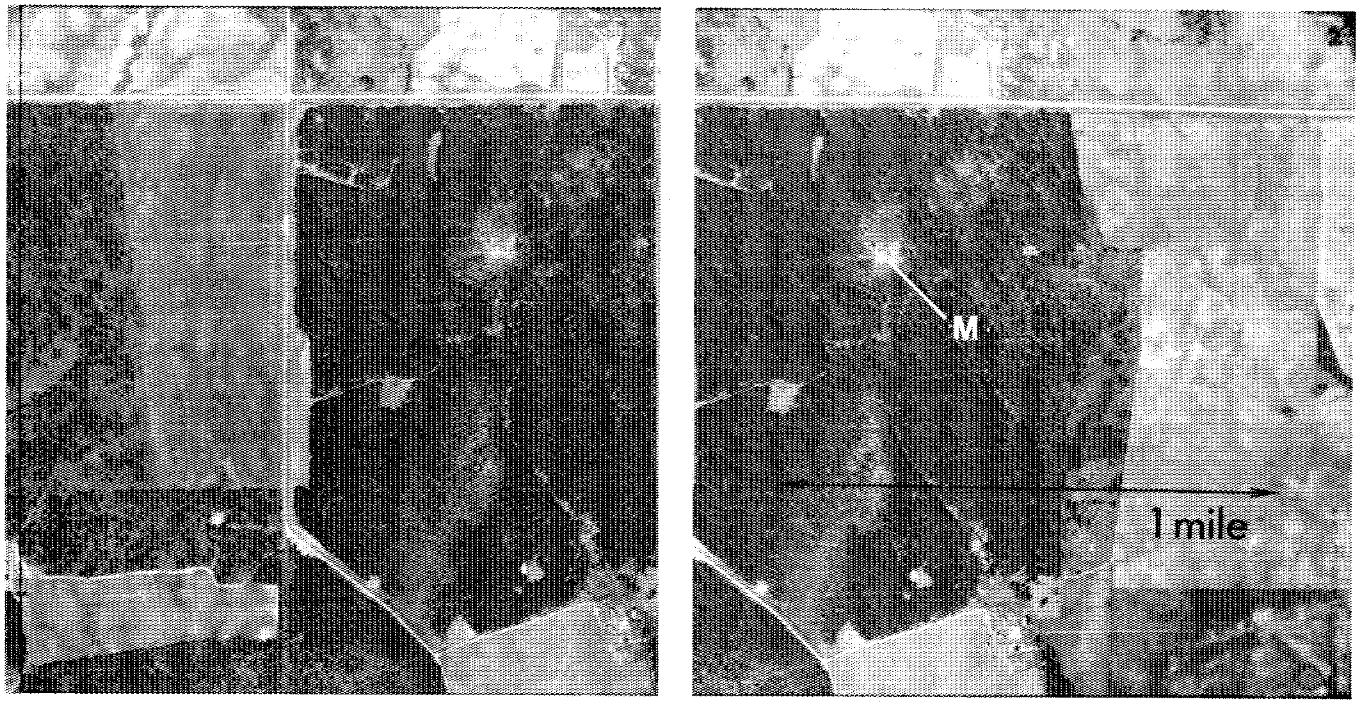


PLATE 2. Stereo pair of Evansburg - Hillside seepage (B-1) deposit. M - marl and tufa forming a carbonate terrace on a hillside. Air photo expression is an open, white bog. Most hillside seepage deposits do not show this much aerial photo expression.

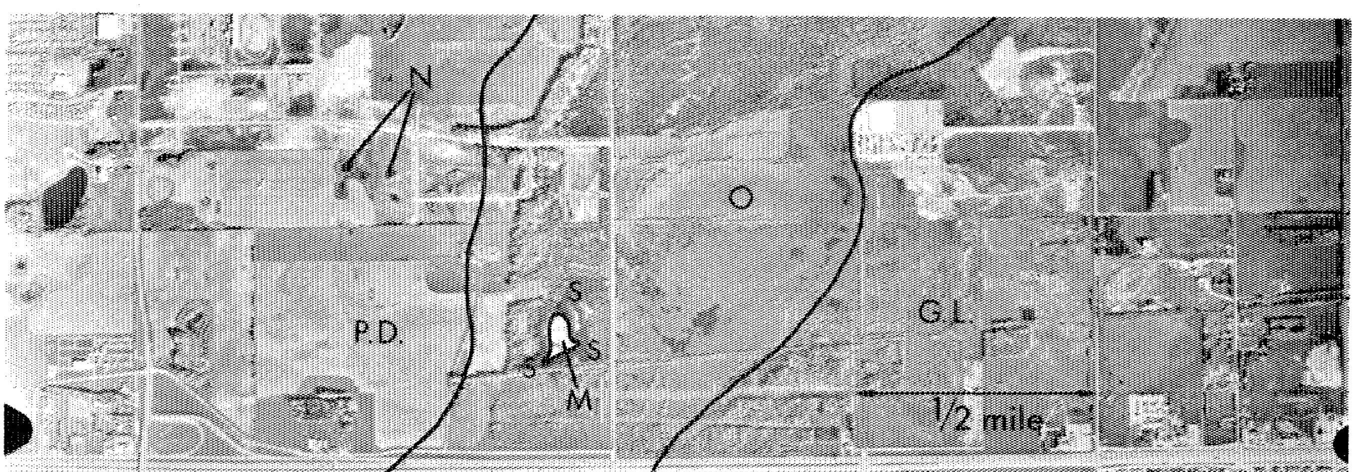


PLATE 3. Winterburn A deposit - Seepage ponded type (B-2) deposit. P.D. - pitted deltaic sediments (sands, silts, gently rolling), G.L. - glaciolacustrine silt and clay, O - organics and peat, M - marl bottomed pond (deposit site), N - normal (acid or neutral) ponds, S - note abundance of black spruce around deposit, suggesting active groundwater discharge.

water flow systems flowing through permeable surficial sediments (Fig. 4). The algae *Chara* sp. appears to play an important role in deposition as indicated by abundant algae remains.

The marl is non-tufaceous, of fair to good quality, and is usually present in intermediate to large quantities.

C. *Shoreline-fringe* deposits are limited to the subaqueous, near-shore environment or along paleo shorelines of lakes that previously had higher water levels. The actively precipitating deposits are found in boggy areas around sheltered bays of large lakes. The lakes are located adjacent to areas of high relief suggesting they are the terminus of well-developed, local groundwater flow systems, with the marl being deposited in the near shore zone by thermal stratification. Air photo expression is poor for inactively and fair for actively precipitating deposits. Distinguishing a marl bog from a normal acidic bog (Plate 5) is difficult. Characteristically, organic sediments grade lakeward to marls of high C.C.E., containing abundant *Chara* sp. debris. Shoreline fringe deposits are of variable quality, and are intermediate to small in size.

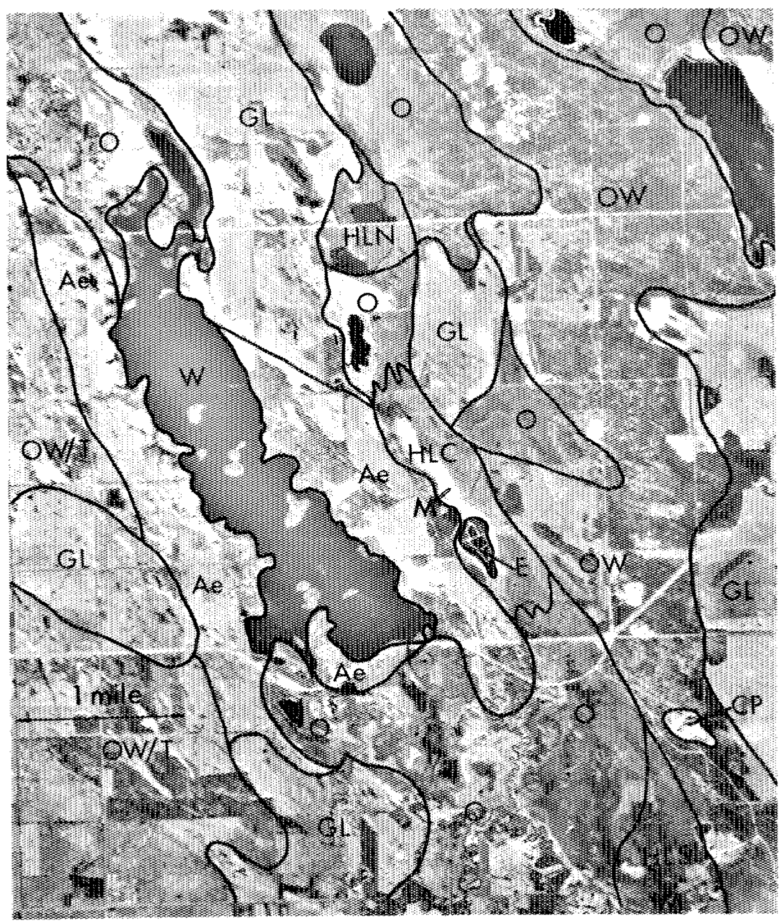


PLATE 4. Halfway Lake central (H.L.C.), Halfway Lake northern (H.L.N.), and Halfway Lake southern (H.L.S.) deposits - Seepage ponded deposits. M - marl bottomed lakes and ponds (very white), W - Wakomao Lake (dark bottomed no marl); O.W. - outwash sand and gravel, G.L. - glaciolacustrine sand, silt and clays, O - organic area, Ae - Aeolina sands, OW/T - outwash (thin and discontinuous) over till, C.P. - Hough Cement Ltd. plant, E - excavated portion of Halfway Lake central deposit for use in cement production. Figure shows complete surficial geology.

The inactively precipitating shoreline deposits were formed in an environment similar to that of the actively precipitating deposits. They have subsequently been left on dry land after lake waters receded. The size and properties of these deposits are similar to those of the active deposits, except that organic content has been reduced through decay and the deposits may not be water saturated. These deposits seldom have expression on air photos, unless ploughing has brought the white marl to the surface.

D-1. *Abandoned channel—glacial:* Deposits are found in abandoned glacial meltwater channels that are characteristically flat bottomed and contain sluggish streams and/or small lakes or sloughs (Fig. 4). These channel deposits are usually flanked by upland areas covered by coarse-grained surficial materials of considerable thickness. Marl is deposited by groundwater moving through the surficial sediment aquifers and precipitation of marl is thought to be by physico-chemical means aided by *Chara* sp.

The composition of these deposits ranges from muddy to pure marls (Fig. 3) with tufa nodules sometimes present. Most deposits do not show evidence of active marl pre-

PLATE 5. Raven deposit - Shoreline fringe - actively precipitating marl (C-1) Tp. 36, Rge. 4, Sec. 3 W4 D - sand dunes, M - marl at surface as "fringes," C - calcareous bog, carbonate mixed with peat, maximum 40 percent C.C.E., A - normal acid peat bog, no marl.

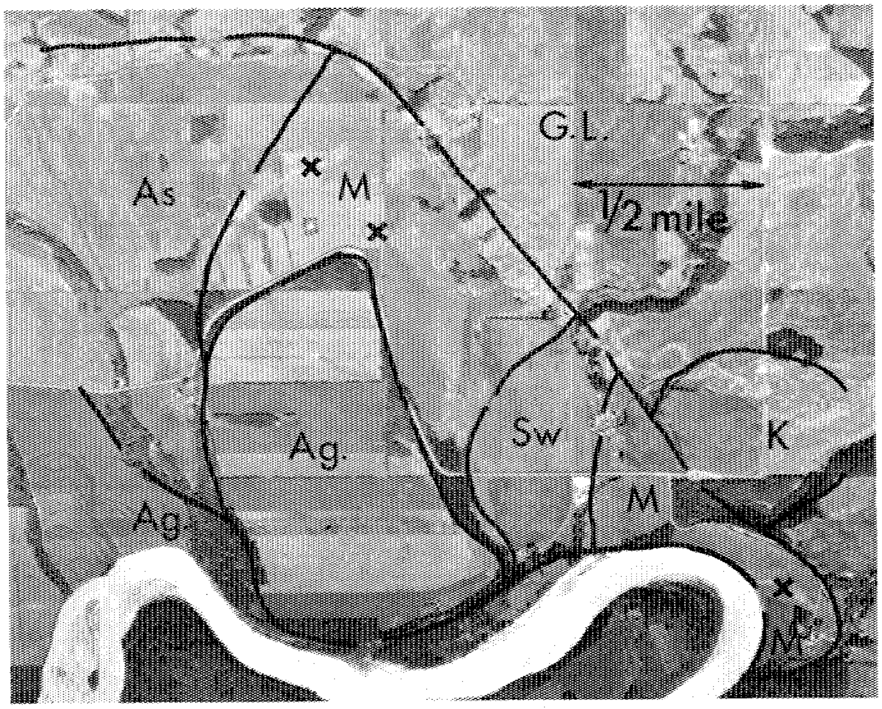


PLATE 6. Duffield deposit - Abandoned Channel - Oxbow lake type (D-2); G.L. - glaciolacustrine sand and clays, moderately rolling; K - kame, moderately well sorted sands, minor gravels; Ag - Recent alluvial gravels, minor sand, As - Recent alluvial sand, silt and clays; Sw - slopewash (silts and clays); M - marl, varying grades and thicknesses; x- surface showing of marl.

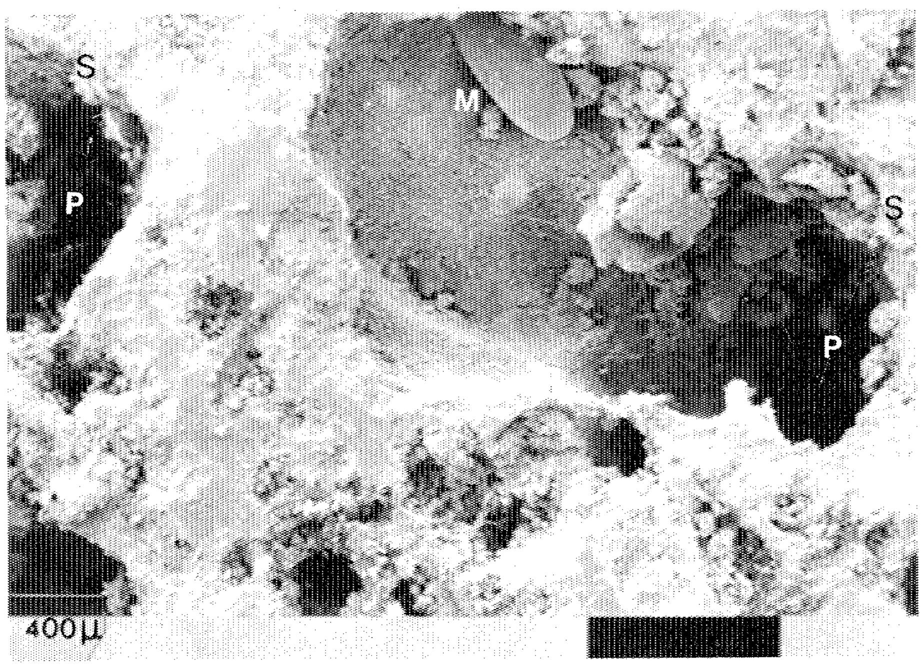


PLATE 7. Tufa from Benalto deposit. Scanning Electron Microscope (S.E.M.) micrograph (magnification 53X, Black bar ≈400 μm) S - large sparry calcite crystals growing into a cavity (see magnification, Plate 8), M - finer grained micrite, P - pore spaces within rock

cipitation, are small to intermediate in size, and are of variable quality.

D-2. *Abandoned channel—oxbox lake:* Deposits have most of the attributes of the D-1 group except that they have formed in former oxbow lakes associated with Recent rivers (Plate 6). This implies a younger age of formation than the D-1 group.

E. *Floodplain:* Marl deposits were found in floodplain environments of Recent streams and rivers. These few deposits are typically muddy marls to pure marls less than 50 cm in total thickness. They occur as small discontinuous deposits. They have no potential value as sources of agricultural lime.

F. *Recent lacustrine calcareous sediments* are found in lake basins in which the lakes lie in areas of outwash, aeolian, or pitted outwash terrain. These deposits commonly contain less than 50 percent C.C.E. and are of no economic value.

G. *Alkali flats* are found in east-central and southern Alberta as extensive salt accumulations and are often present in dried-up intermittent lakes and ponds or along streams. These deposits, of mixed carbonate and sulfate salts, are of no value as sources of calcium carbonate since they form very thin deposits (less than 20 cm), are of very low quality (20 to 49 percent C.C.E.), and are discontinuous.

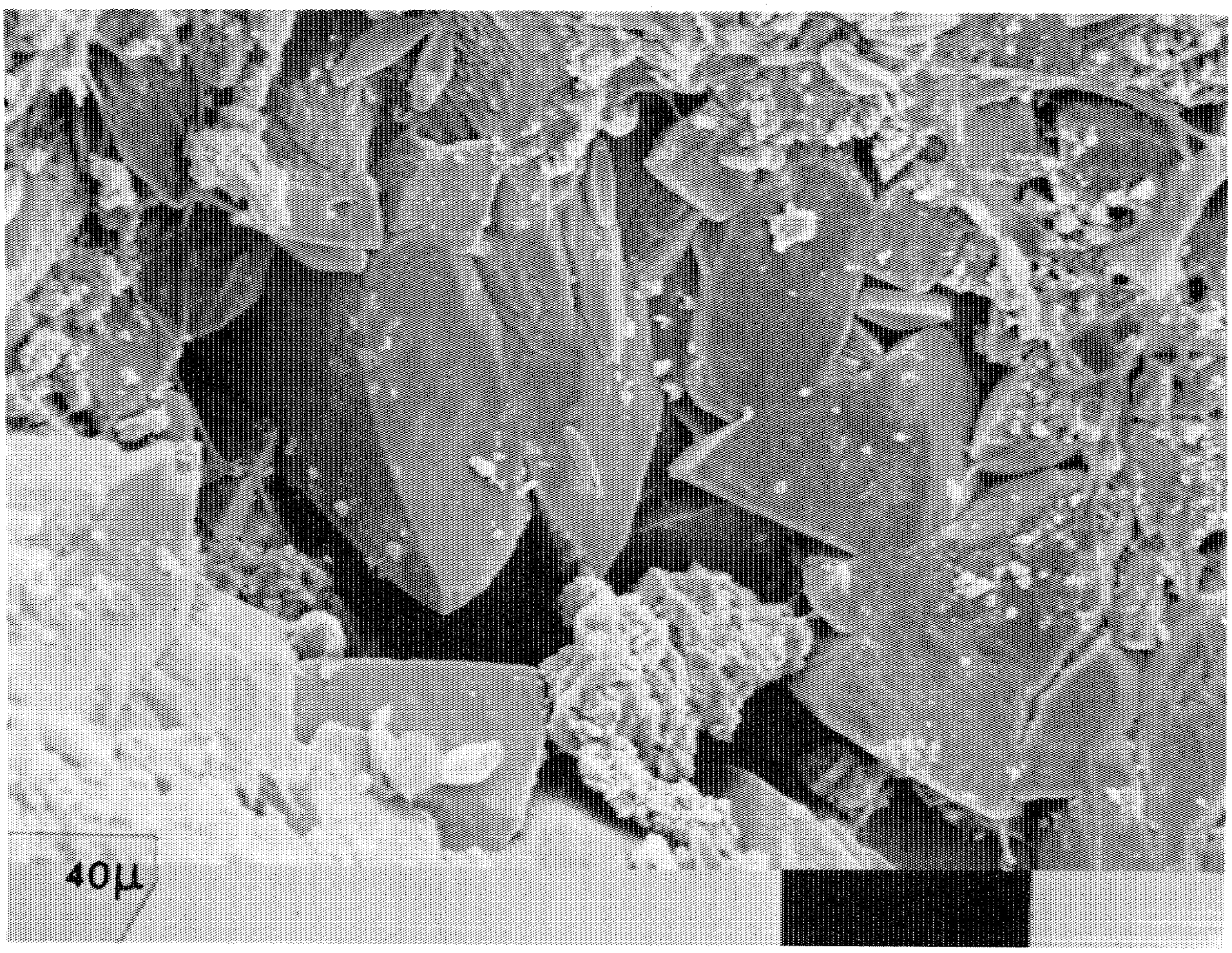


PLATE 8. Magnification of sparry calcite crystals in Plate 7, euhedral 50 to 60 μm in size. S.E.M. micrograph (magnification 525X, Black bar $\approx$40 μm).

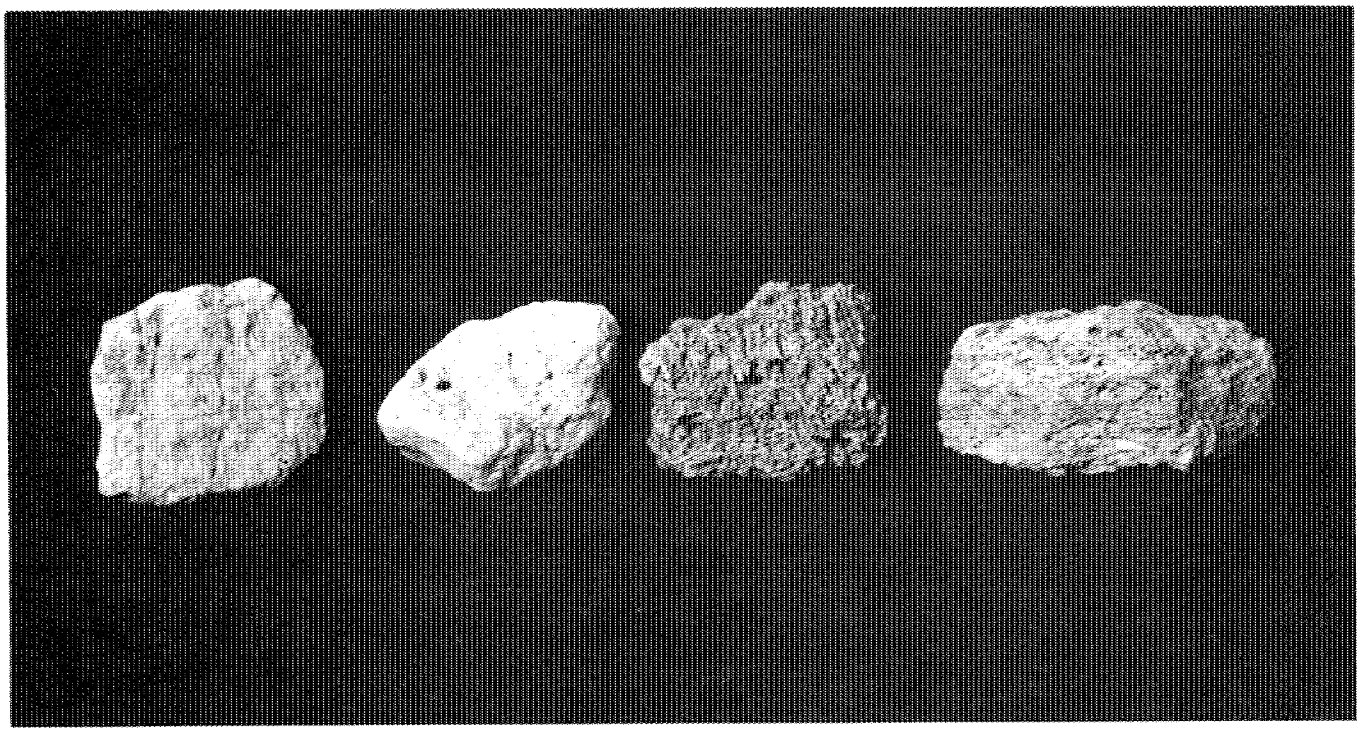


PLATE 9. Marls and Tufas: Extreme left and left center - typical marls; shell fragments and fine-grained friable texture. Right center and extreme right - tufas, showing spongy, porous texture. Note calcified moss and plant remains in tufa.

H. *Preglacial* deposits include all occurrences of freshwater calcium carbonate thought to be older than pre-classical Wisconsin in age. Deposits are generally thin (<50 cm), of poor quality, discontinuous, and of no economic interest.

COMPOSITION OF DEPOSITS

Tufa normally consists of over 90 percent calcite and calcified plant remains (Plate 9).

Marl consists of calcium carbonate, mud, and organic materials (Figs. 3, 10, 29, 35, Plate 9). Marls commonly contain less than 20 percent organic material and the majority less than 35 percent mud. The clay mineral content of the muds is less than 5 percent in most cases. The mud portion is largely made up of diatoms, with detrital quartz present only in the muddy marl class of sediments. The carbonate fraction is composed entirely of calcite in most samples, although some contain calcite and aragonite, and in a few deposits aragonite predominates. The aragonite is likely contributed by gastropod shells. The organic content is less in older and better-drained deposits than in younger, wetter ones.

The classical definition of marl, as a sediment composed of roughly equal portions of calcium carbonate and clay is not applicable to most marls in Alberta.

PETROLOGY OF DEPOSITS

Tufa

The tufa deposits approximate "sparite" of Folk (1959). They characteristically consist of crystals of calcite growing into cavities, left by decaying vegetation. Adjacent to the cavities, the crystals are usually large (up to 40 μm), anhedral sparry calcite. Away from these cavities, the calcite consists of microspar and micrite, with grains less than 4 μm long (Plates 7 and 8). Much of a tufa deposit is made up of tufa nodules, which probably grow around some initial center of crystallization such as a sand

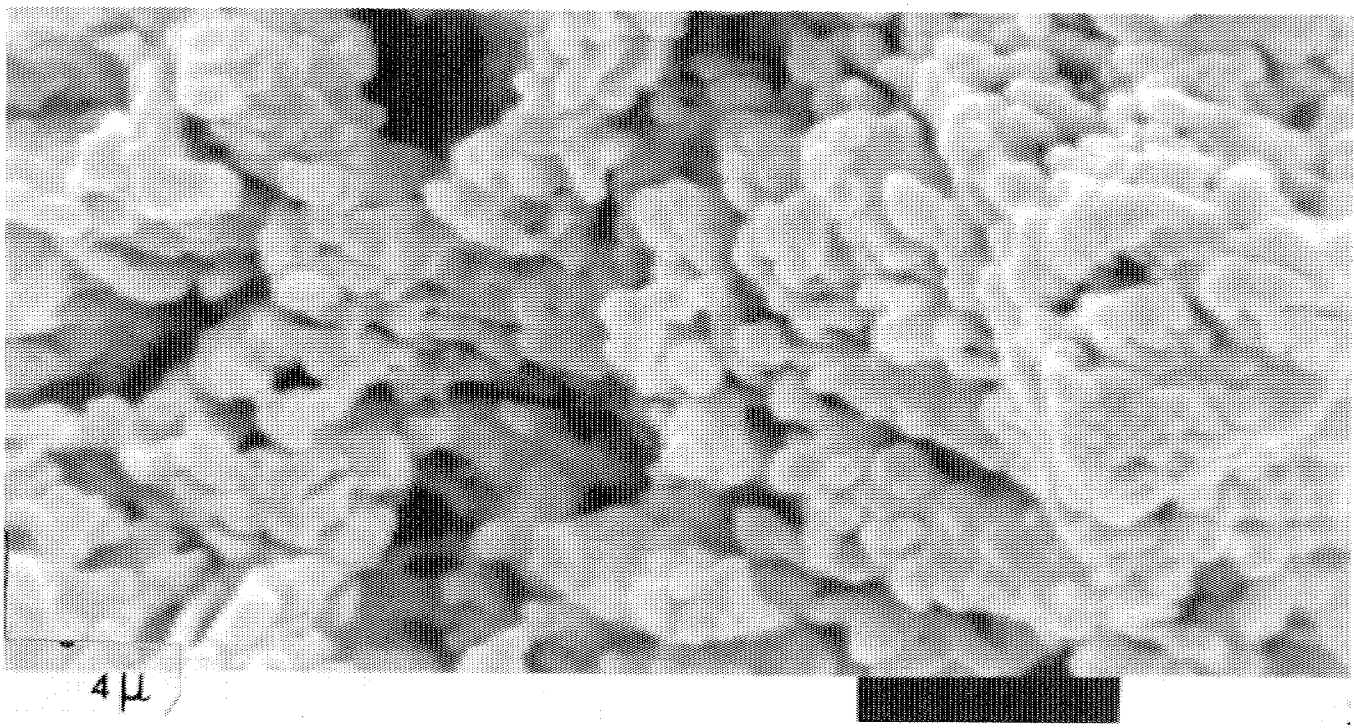


PLATE 10. Scanning Electron Microscope micrograph of Halfway Lake marl, 5125X magnification (Black bar is 4 μm long - approximately). Subhedral to anhedral crystals, most less than 2 μm (micrite).

grain, or plant fragment. Calcified plant remains are the only fossils in the tufa deposits.

Marl

Marls can be described as a "fossiliferous micrite" (Folk, 1959). These deposits consist of loosely packed micrite with crystals ranging in size from 1 to 10 μm with most about 4 μm (Plate 10). Crystals are commonly anhedral to subhedral with some showing evidence of having undergone dissolution. Commonly the marls are poorly cemented, loose, and highly porous. Fossils include *Chara* sp. "stalks" and "seeds," molluscs, ostracods, and diatoms (Plate 11).

USES OF MARL

AGRICULTURAL LIMING

This study was initiated to find marl and tufa deposits suitable for use in agricultural liming. Specifications for liming materials are set out by A.S.T.M. standard C-602-69. Calcium carbonate equivalence (C.C.E.) is the most important factor with magnesium content and texture of secondary importance. Liming-grade marl should have a C.C.E. of 70 percent or higher (Wayne, 1971) and should be a dry, unconsolidated material in order to pass through spreading machinery. Most Alberta marls meet the specifications for agricultural lime. The tufa deposits have an adequate carbonate content, but most would require crushing to meet the size requirement.

Liming to reduce soil acidity is just starting to be practised on a large scale in Alberta, and, with an increasing awareness of the acid soil problems in Alberta, demand for agricultural lime will likely increase in the future. In 1978 marl for liming was available in Alberta at prices ranging from \$8 to \$10 per short ton F.O.B. from the quarry. However, only two sources of supply have been developed for this purpose.

CEMENT

Marl deposits have been used to produce cement on a very limited scale in Alberta. Specifications for portland cement vary, although the raw material must contain less than 5 percent $MgCO_3$ and the final cement product contain a certain percentage of silica, iron oxide, and alumina. Most Alberta marl deposits contain less than 5 percent $MgCO_3$ and the silica and alumina content is often variable within a given deposit. Only one company, Houg Cement Ltd. at Halfway Lake (Plate 4), currently uses marl for cement production.

The main problems with using marl for cement manufacture are the difficulty of maintaining quality control while mining the marl and its high moisture content. A great deal of energy is required to dry the marl in the cement-making process. Mixing marl with pure limestone to maintain a low $MgCO_3$ content for manufacture has been suggested by Thorvaldson (in Kupsch, 1956). Sparks and Meadus (1974) suggest a beneficiation method to separate the calcium carbonate of marl from the organic material and siliceous diatoms.

OTHER USES

Marl and tufa have potential for a number of miscellaneous uses such as: building stone (tufa), animal feed supplements, industrial fillers, paper manufacture, paints, rubber industry, pesticides, road stabilization, manufacture of lime (CaO), chemical industry and sulfur dioxide pollution control (Guillet, 1969; Harvey *et al.,* 1973). In the early pioneering days of Alberta, "lime," "marl," and "shell bed" deposits were used to plaster log cabins and as chicken grit.

RESERVES, MINING, PROCESSING, AND MARKETING

Resource estimates for deposits in Alberta which appear in Part II are given as cubic metres of in situ material. Guillet (1969) plotted the relationship between moisture content of crude marl and the

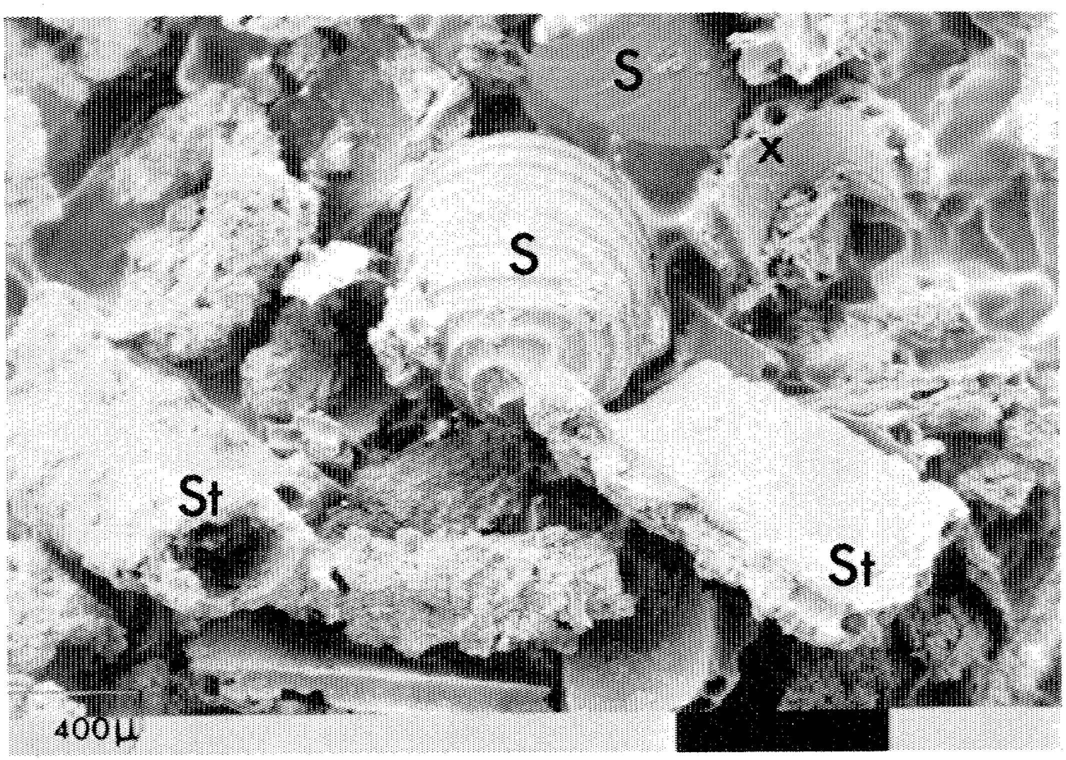


PLATE 11. Scanning Electron Microscope micrograph of marl, from Big Lake (at Atim Lake) deposit *Chara* sp. remains. S - calcified "seeds," St - calcified "stalks," X - cross-section and inner wall of "stalk" (Blackbar is 400 µm, 53X magnification.

weight of the marl per cubic yard in a dry state and this has been converted to tonnes per cubic metre assuming a specific gravity for dry marl of 0.95 (Fig. 5). Using this figure, the tonnage of dry marl can be estimated, if the moisture content and volume are known (see A.S.T.M. - Designation C-602, 1969, Reapproved 1975 for moisture measuring procedures). If, for example, the moisture content is 50 percent, the dried marl will weigh 0.475 tonnes/m³.

Mining marl for cement in the past was done by draglines or suction dredges from barges, with the slurry transported to shore through a flexible pipeline. Quality control was difficult to maintain. Today, Houg Cement Ltd. mines marl in the winter months by dragline and maintains better quality control than is possible using dredging techniques.

Beneficiation is discussed by Guillet (1969), Sparks and Meadus (1974), and Thorvaldson (in Kupsch, 1956) and can include: removal of organics by flotation, sieving out coarse sand and sizing using air classifiers. Drying marl is difficult due to higher water content and high fines content.

There are many potential uses for marl in Alberta, although the present consumption is small. Current demand for agricultural marl is small, but a larger market could develop if soil liming becomes an established agricultural practice. Uses for cement manufacture will probably be restricted to the existing plant because cement manufacture requires a large deposit of high-quality marl. The high energy costs associated with drying marl also make it unattractive for cement manufacture.

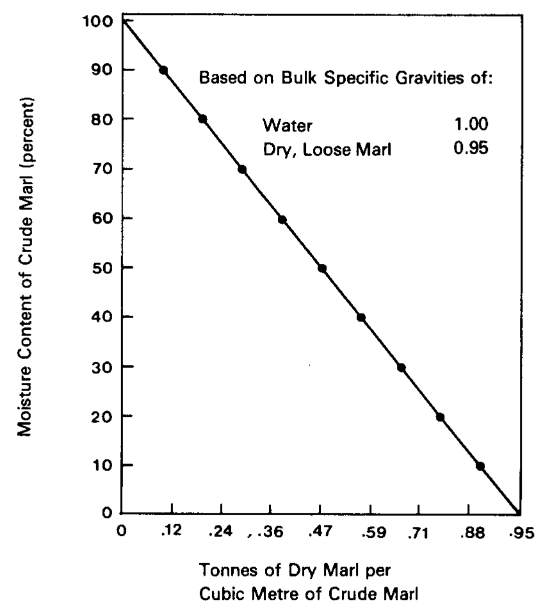


FIGURE 5. Estimation of dry marl available in the wet crude.

PART II

DESCRIPTION OF DEPOSITS

EXTENT OF SURVEY

In general, the geographic extent of the survey was related to the acid soil areas of Alberta (Fig. 1), because of the need for agricultural lime within these areas. The province was divided into five regions (Fig. 2) and exploration was conducted in all regions except the west-central area.

Fieldwork was concentrated in agricultural areas with good access. Individual deposits will be discussed by the five regions and with reference to the National Topographic System (N.T.S.) (Fig. 2). Figure 38 and Table 9 summarize the findings of this study.

Reports of marl or tufa at inaccessible locations in the Rocky Mountains and Foothills were not investigated.

TERMINOLOGY USED

The term "showing" is used when a single testhole penetrated calcareous sediments or marl and no follow-up work was done. The term "deposit" is used for sediments with a C.C.E. of at least 50 percent in which areal extent and thickness were determined. "Reports" are reported occurrences of marl and tufa that were not investigated. All symbols and abbreviations used in maps and figures throughout this section appear in Appendix 10.

NORTHWESTERN ALBERTA

GRANDE PRAIRIE (N.T.S. SHEET 83M)

Four deposits, five reports, and one showing of marl were located within this area and the three deposits having economic potential are discussed.

The surficial deposits of the map sheet are mainly glaciolacustrine, with till deposits at lower elevations and till in the highlands (Odynsky *et al.*, 1961; Odynsky *et al.*, 1956).

Most major lakes in the area were sampled and contain weakly calcareous silts and clays (<20 percent C.C.E.). The most promising area for additional exploration is in Township 78, Ranges 9 to 13, West of the 6th Meridian and in the Saddle Hills. These are areas of high, local relief with thin drift cover (Carlson and Hackbarth, 1974) and many of the known local deposits originate where groundwater discharges at the drift-bedrock contact.

Deposit 1 - Spirit River (N.T.S. 83M/15)[1]

A seepage (B-1) marl deposit is found south of the Spirit River townsite on the side of a bedrock upland in 5,6-16-78-6-W6 (Fig. 6). This deposit, first described by Holter (1974b) and re-examined by the author, forms a moist, vegetated area on a cultivated hillside sloping gently towards the Spirit River where the groundwater is probably discharging from the Cretaceous Badheart Formation, a sandstone cemented by calcite and iron oxide.

Eleven testholes were drilled (Appendix 4) and a fairly accurate assessment of the deposit is possible. The highest quality marl is in testhole 4 (83 percent C.C.E.), with most samples averaging between 40 and 50 percent C.C.E. When tested in October 1973, the moisture content ranged from 18 to 24 percent (Holter, 1974b). The color of the marl ranges from white for high-quality samples to brown for low-quality ones.

Holter found that in testhole 10 approximately 21 percent of the marl weight is fine sand or larger (>.063 mm) with the balance of the sample silt and clay-sized material (<.063 mm). Microscopic examination of the sample revealed tufa fragments, ostracods, gastropods, *Chara* sp. stalks, and other detrital material. With an estimated average thickness of 0.5 m of marl (and calcareous sediments) having an average C.C.E. of 40 percent, the deposit contains 42 800 m³ of material. The deposit is dry enough to quarry and access is good over country roads.

Deposit 3 - Bay Tree Deposit "A" (N.T.S. 83M/13)

This deposit was examined by Holter (1974b) and his findings are summarized here. This seepage ponded (B-2) deposit is in a shallow pond near the confluence of two streams in 3 and 6-15-78-12-W6 and lies 1 km north of the nearest gas-well service road. The pond has a distinctly yellowish-white bottom when seen from the air, in sharp contrast to the

[1] This notation will be used throughout this section. The reader is referred to Table 9, under N.T.S. map sheet 83M, deposit number 1. The N.T.S. 1:50 000 scale map sheet 83M/15 covers this area.

dark color of most lakes in the region. The pond is devoid of aquatic vegetation (Holter, 1974b). Regional geology of the area is mainly till overlying the shales of the Cretaceous age Puskwaskau Formation.

Two testholes were drilled by Holter; the hole at the north edge of the pond showed 2 m of marl with 80 percent C.C.E. or greater overlying 1 m of sediment having a C.C.E. of 40 percent. All samples from this testhole were water saturated. Gastropods, ostracods, and *Chara* sp. remains were observed throughout the samples. Grain-size analyses show about 20 percent of the material to be fine-sand sized or larger (>.063 mm), 65 percent silt, and 15 percent clay (<.002 mm). The second testhole, about 20 m northwest of the edge of the pond, penetrated 1.5 m of 35 to 47 percent C.C.E. sediments below 1.5 m of organic detritus.

Holter estimated the marl deposit to be approximately 80 m in diameter and 2.5 m thick, containing an estimated volume of marl of 11 000 m³. To excavate the marl would require draining the pond and constructing an access road 1 km long.

Deposit 6 - Demmit (N.T.S. 83M/15)

This is a typical hillside seepage (B-1) deposit situated on a hillside heavily wooded with poplar and birch adjacent to a small stream in 10-16-74-13-W6. Access to the site is via overgrown wagon trails established by early settlers who used this marl as a source of chicken grit and whitewash material.

The description of the deposit is from Holter (1974b). Surficial geology is about 16 m of till with a thin covering of outwash sand overlying the Cretaceous Wapiti Formation. Carbonate-rich groundwater characterizes the area (Hackbarth, 1978).

Holter sampled an overgrown pit at the site that showed 105 cm of 92 percent C.C.E. marl overlain by a thin layer of organic sediment and underlain by gray-red sands. Moisture content at the time of sampling was 29 percent and Mg/Ca ratios ranged

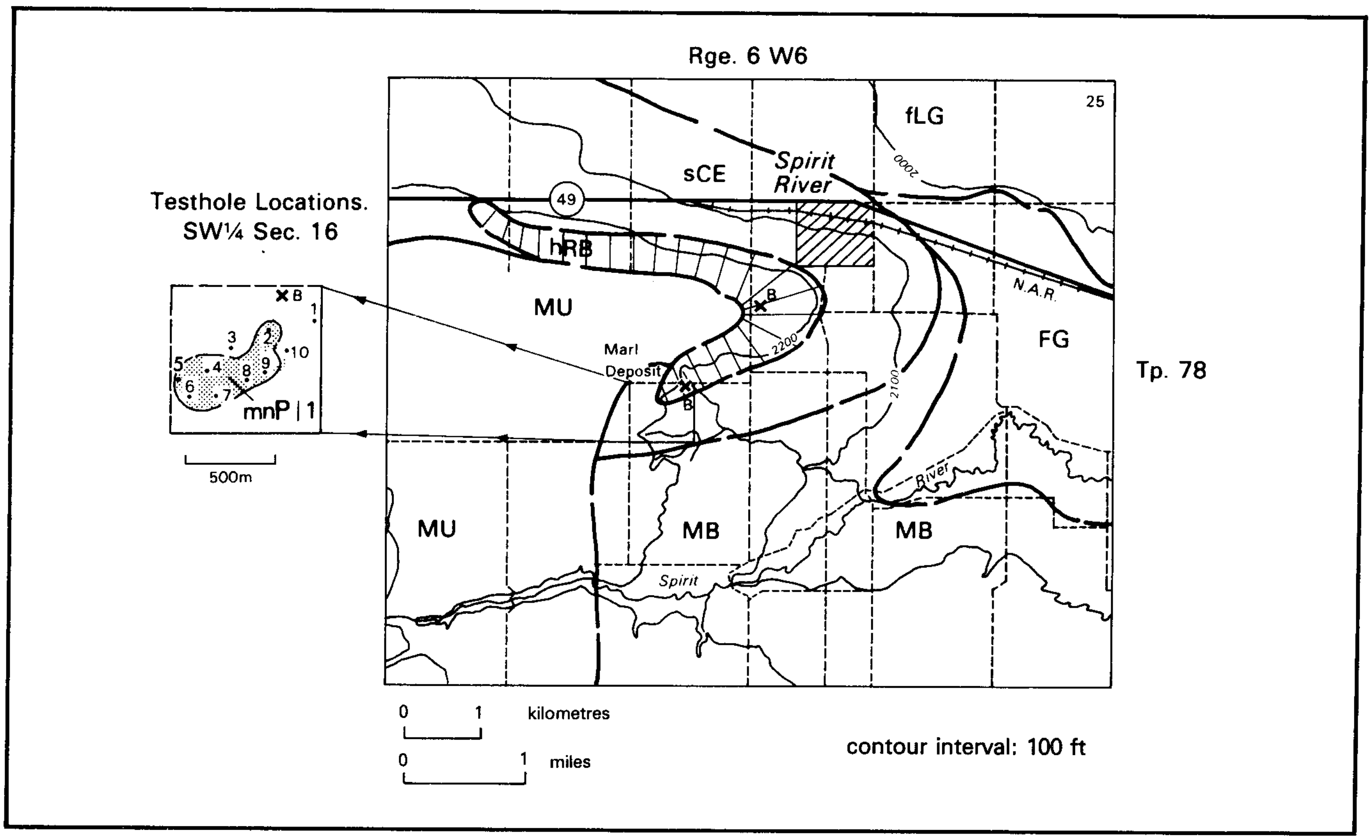


FIGURE 6. Location, topography, and surficial geology - Spirit River Deposit (see Appendix 10 for legend)

from 1:35 to 1:92. Grain-size analyses showed the marl to consist of 53 percent sand and granule-sized material (4 - 0.063 mm), 41 percent silt and 6 percent clay-sized (<.002 mm) material. Microscopic examination showed most coarser material to be tufa. Holter (1974b) estimated 1759 m^3 of marl, based on an estimated deposit thickness of 0.7 m and a radius of 30 m.

Holter suggested that the hillside northwest of the Chain Lakes valley may contain additional deposits, precipitated where groundwater moving from the highland areas to the northwest surfaces near the Chain Lakes. The cover of organic sediment at the Demmit deposit, which made recognition of the deposit difficult, could also obscure similar deposits in the region. The organic cover also suggests that marl is not being precipitated at the Demmit deposit at present.

WINAGAMI (N.T.S. SHEET 83N)

Although five deposits were found in this map area (Table 9), only two deposits that have economic potential are described. Geology of the region is characterized by highland areas covered with till and low-lying areas predominantly covered by glaciolacustrine sediments (Jones, 1966). Areas of extensive glaciofluvial outwash are confined to the Eaglesham-Tangent and High Prairie regions (Jones, 1966).

Road access in the Winagami area is limited to agricultural areas just beginning to be developed. The main exploration areas were Valleyview-Crooked Creek, High Prairie, and the Falher-Eaglesham regions. Over half the map area is inaccessible by road.

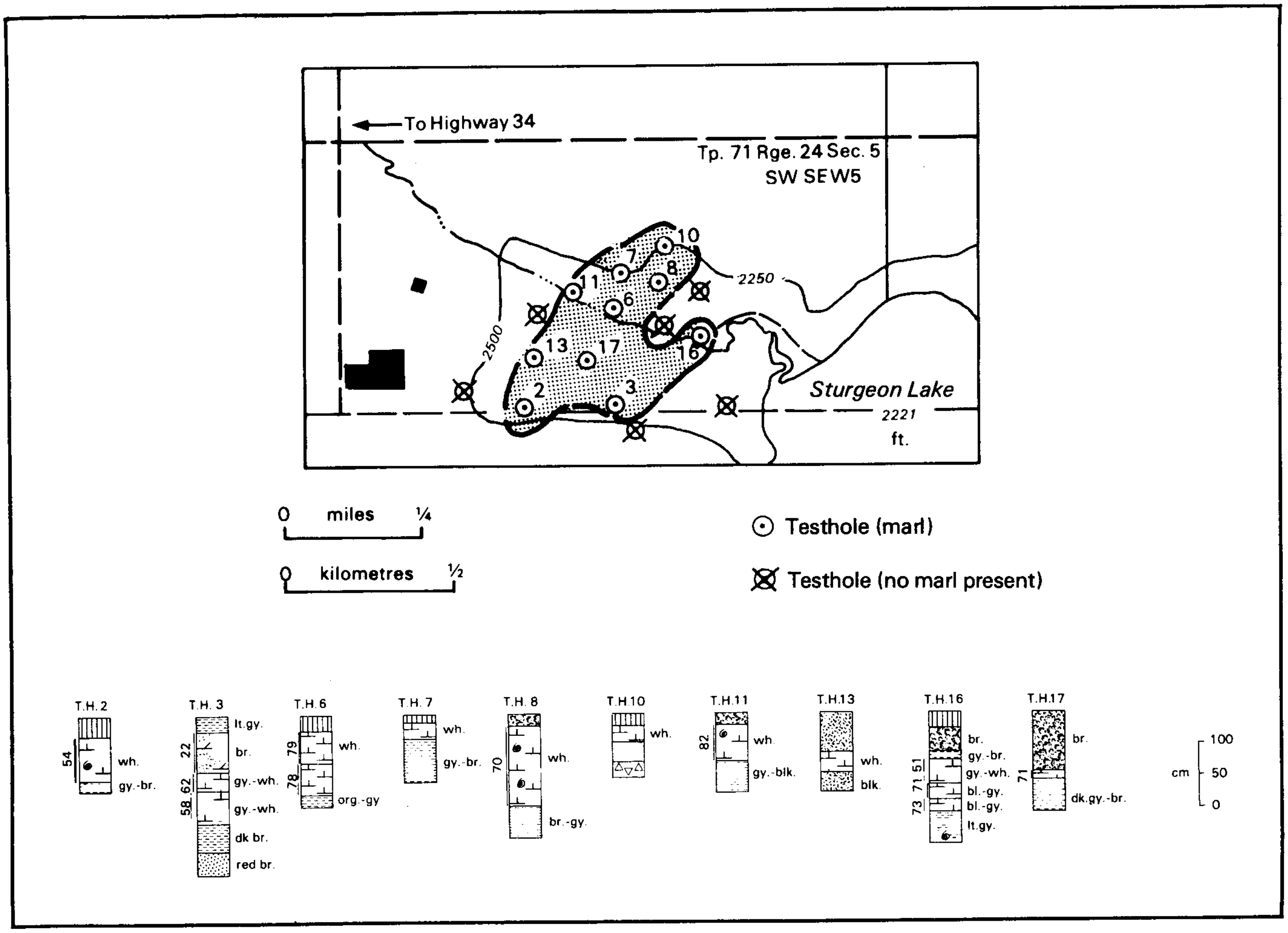
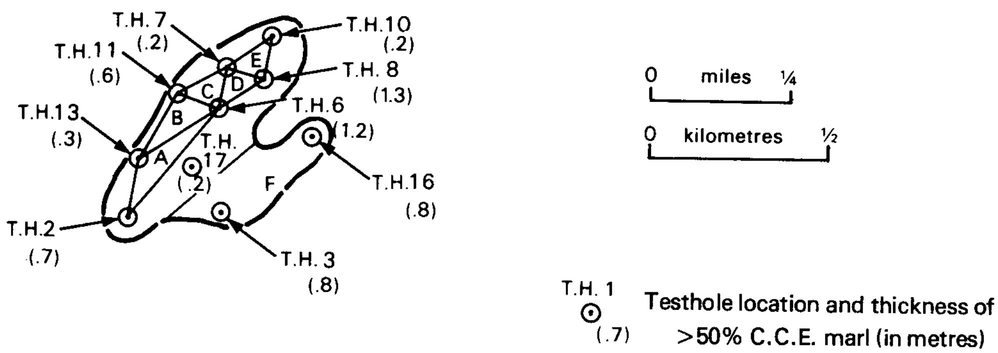


FIGURE 7. Testhole data, location, and extent - Sturgeon Lake marl deposit



Area	Avge. Thickness	C.C.E.	Area (m²)	Volume (m³)
A	.7 metres	53-78	30,880	21,616
B	.7 metres	53-82	25,728	18,009
C	.65 metres	78-82	12,900	8,385
D	.9 metres	70-78	12,000	10,800
E	.55 metres	70	13,330	7,332
F	.80 metres	50-72	33,602	26,881
* Total				93,023

*Volumes "in situ"

FIGURE 8. Reserve calculations - Sturgeon Lake deposit

An aerial survey conducted in the Crooked Creek-Snipe Lake-Valleyview-New Fish Creek areas showed that known marl deposits are identifiable from the air when cultivation has brought marl to the surface; however, differentiating marl from gray wooded soil was difficult. Major lakes in the area were surveyed by air and only Snipe Lake showed a whitish fringe (17-71-18-W5) along the shoreline. It was not investigated because it was inaccessible.

Future exploration should concentrate in the hills north of Sturgeon Lake and the hills south of Snipe Lake for seepage (B) deposits. Broad glacio-lacustrine and till plains are not favorable exploration areas because local lakes and swamps contain organic or detrital sediments rather than marl.

Deposit 3 - Sturgeon Lake (N.T.S. 83N/4)

The Sturgeon Lake deposit is a shoreline fringe (C) type situated in a marshy area which was a bay of Sturgeon Lake when the water level was higher (5-71-24-W5). Access to this deposit is very good by farm roads and the deposit is situated in a reasonably dry location, although the water table is close to the surface and rises to the surface at Sturgeon Lake. Drift less than 3 m thick overlies Wapiti Formation bedrock at the site and the reddish-brown sands at testhole 3 (Fig. 8) may be bedrock.

Groundwater in this region is characterized by Ca^{+2},SO_4^{-2} waters in the surficial aquifers of the region and Na^+, HCO_3 bearing waters in the main sandstone bedrock aquifer of the region. Discharge of bedrock and surficially derived groundwater is thought to be the cause of the marl accumulation.

Seventeen testholes drilled in the area (Fig. 7) indicate the marl to be restricted to a northeast trending belt between the surrounding uplands and the wet marsh fringing the lake. No marl was encountered in this marsh. The marl varies in thickness from 0.2 to 1.2 m and the C.C.E. values are from 53.5 to 82.0 percent. Most samples are nearly pure marl (Fig. 10); the major contaminants are silica (quartz and diatoms) 9.5 percent, clay minerals 4 percent and organic material 3 percent (Tables 10 and 11).

Reserves for the Sturgeon Lake deposit are summarized in Figure 8. The quality of the marl was assumed to be between 50 and 80 percent C.C.E. to arrive at the reserve volumes and thicknesses averaged from testhole data for the five areas shown in Figure 8. The deposit is characterized by marked variability in the quality and thickness of the marl, which may make extraction difficult. Also, production of the marl would transform a large area of pasture land into marsh by lowering the land surface below the water table. Despite these disadvantages, the deposit is suitable as a source of lime for soil liming with a total volume of 93 000 m^3 of marl available, having an overburden less than 0.3 m thick.

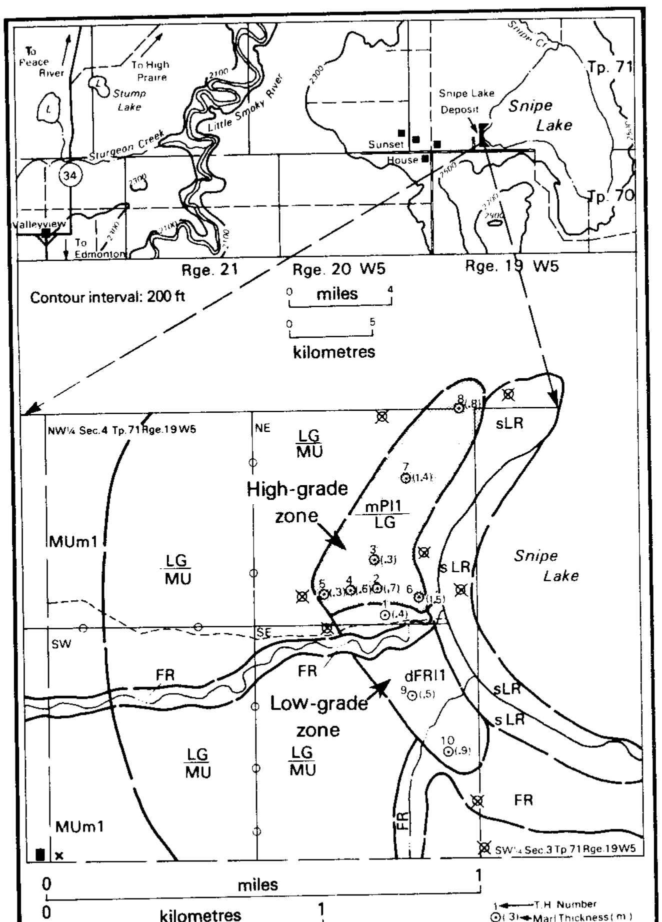


FIGURE 9. Location, access, surficial geology, and testhole locations - Snipe Lake deposit.

Deposit 5 - Snipe Lake (N.T.S. 83N/2)

The Snipe Lake deposit, on the western shore of Snipe Lake (4-71-19-W5), is in an area that was formerly a bay when the lake stood at a higher level. Most of the deposit is cultivated, and was recognized when ploughing brought marl to the surface. The deposit is accessible by a farm road.

Surficial geology of the area, presented in Figure 9, is characterized by a variable thickness of drift overlying the interbedded sandstones and shales of the Cretaceous Wapiti Formation. The drift is primarily lacustrine sediments with interbeds of sand and gravel less than 5 m below the surface. Away from the lake, the drift is mostly till, which is thin in highland areas to the south and is as much as 30 m thick at Sunset House, west of Snipe Lake.

The hydrogeological setting of the area is poorly understood; however, groundwater flow is apparently from the hills south of the lake northward into Snipe Lake (Borneuf, pers. comm.). Groundwater is very near the surface at the deposit. Chemistry of the bedrock waters is predominantly Na^+, K^+, and HCO_3^-, whereas the surficial aquifers contain Ca^{+2} and HCO_3^- rich waters. The marl deposit is interpreted to be a Shoreline Fringe (C) deposit, with the carbonate source being the shallow surficial aquifers. Marl deposition occurred when Snipe Lake stood at a higher level as indicated by beach sands overlying the marl in places.

The deposit was defined by 18 testholes; some detailed logs appear in Appendix 5. The marl, found in a belt paralleling the present lake shore, is thickest near the lake and pinches out to the west.

Towards the lake, the marl grades into lacustrine sands that overlie calcareous clays. The marl varies in thickness from 0.3 to 1.5 m and C.C.E. values range from 36.5 to 79.0 percent. The overburden is about 20 cm thick.

Microscopic examination of marl samples showed gastropods, a few *Chara* sp. remains, ostracods, and plant and rock fragments. The average grain size of the marl is about 4 μm based on photomicrographs with the scanning electron microscope. Analysis of a channel sample (testhole 8) showed the material to be a muddy marl with the main contaminants to be clay (<3 percent) and minor amounts of silica, mostly as diatoms (Tables 10 and 11, Fig. 10).

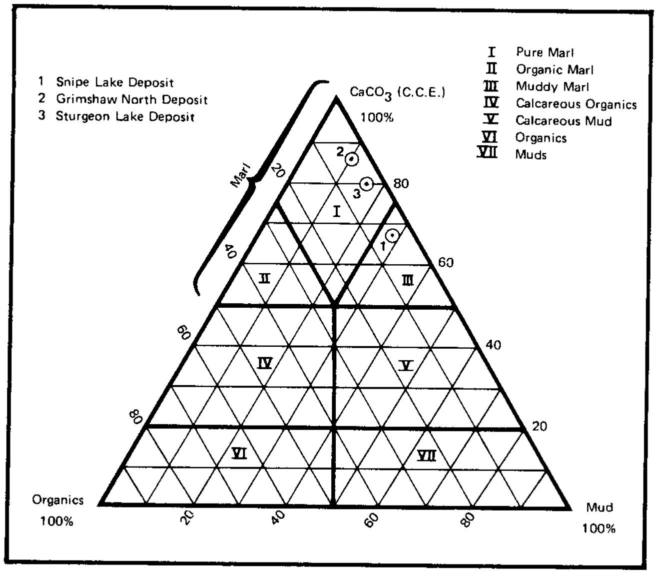


FIGURE 10. Classification of marls from deposits in northwestern Alberta

The deposit can be divided into a high-grade zone of marl north of the small stream entering Snipe Lake and a low-grade zone of calcareous sediments south of the stream. The high-grade zone contains approximately 112 000 m³ of marl with a C.C.E. of 51 to 75 percent, as a wedge-shaped prism 700 m long parallel to the lake shore, 400 m wide and an average thickness of 0.8 m near the lake. The deposit is well drained to the west and drops to below lake level to the east. The low-grade zone contains approximately 94 000 m³ of material having a C.C.E. of 36 to 50 percent and a thickness of 0.5 m or less.

The total volume of marl and calcareous sediments at Snipe Lake is 206 000 m³. The northern zone has good potential for use in agricultural liming as the deposit is of large quantity, adequate quality, has a thin overburden, and is accessible by truck trail. Portions of the deposit may lie below the water table, which will be detrimental to excavation.

PEACE RIVER (N.T.S. SHEET 84C)

Two deposits, two showings, and one report were located in this area (Table 9). The one deposit with economic potential is discussed. Exploration was confined to the settled western half of the map area because access in the east is limited to a few trails.

Additional exploration, if undertaken, should concentrate on the Grimshaw area, this being a discharge zone for the buried Grimshaw gravels. Marl deposits were not found in the Manning or Nampa-Harmon Valley areas and very little potential exists for them to be present. The area near Clear Hills-Dixonville, north of the Whitemud Hills is a regional groundwater discharge area, but testholes around Helen Lake showed only thin calcium carbonate and sodium sulfate salts on the surface, indicating a low potential for marl deposition.

Deposit 1 - Grimshaw (N.T.S. 84C/14)

This deposit was investigated by Holter (1974b) and his findings are reviewed here. The deposit, on a flat plain that slopes gently towards the Peace River (12-14-82-24-W5), is under cultivation in most places. Surficial geology of the area consists of glaciolacustrine sand, silts and clays overlying till (Tokarsky, 1967). Bedrock of the area is the Shaftesbury Formation (a dark gray, marine shale) and the Dunvegan Formation (sandstones), both of Cretaceous age.

The deposit is a mound of marl 3 m high with numerous tufa fragments up to 30 cm long scattered about the site. Drilling by Holter shows the deposit to be lensoidal in shape with a maximum thickness at the center of 4 m and a diameter of 360 m. Samples ran as high as 96.8 percent C.C.E. with most about 85 percent C.C.E. Magnesium:calcium ratios ranged between 1:40 and 1:75. Average moisture content was about 20 percent and the water table is believed to be about 3.5 m below the surface. The marl is fine grained with 85 percent of the material less than 0.063 mm in diameter. Gastropod and ostracod remains were noted, but calcareous algae was not present. Thin sections of the tufa showed it to be mostly sparry calcite growing into cavities left by decayed plant remains. Table 11 and Figure 10 contain additional information on composition from a similar type of deposit north of this one (Grimshaw North deposit).

Holter calculated reserves to be 122 000 m^3 based on an estimated average thickness of 1.2 m and a radius of 180 m. In July 1976, the owners were excavating, stockpiling, and selling some of the marl locally as agricultural 'lime.'

CLEAR HILLS (N.T.S. SHEET 84D)

In the southern half of the map area, the only part of the area accessible by vehicle, two marl deposits have potential for development. Calcareous sediments in glacial outwash, with about 30 percent C.C.E., were found at Lake George (29-83-4-W6) and west of Las Lake (27-83-1-W6).

Potential for marl-bearing lakes is very low because much of the area consists of flat-lying glaciolacustrine deposits, one of the terrain types least conducive to marl formation. Future exploration should be concentrated in the southeast corner of the map area, in and around areas of glacial outwash. Marl deposits might also be found associated with springs and seeps along the flanks of the Clear Hills and Whitemud Hills.

Deposits 1 and 2 - Campbell-Epp (N.T.S. 84D/4, 84D/5)

Two deposits of marl and tufa in this area are named the Campbell (3 and 6-35-83-13-W6) and Epp (16-6-84-12-W6) deposits after the current landowners.

Bedrock in the area is interbedded shale and sandstone of the Kaskapau Formation overlain predominantly by glaciolacustrine sediments or till. The detailed hydrogeology of the site is not known; however, regional groundwater flow is from the highland area in the northwest to the southwest and south towards the Peace and Clearwater Rivers.

The Campbell deposit is a spring-mound type (A-3) at a flowing spring. Three testholes defined the deposit to be a lens-shaped mass havng a maximum thickness of 225 cm (at the center) and an average thickness of 1 m over a radius of 45 m. The 6400 m^3 of marl has a C.C.E. of 84 percent near the center of the deposit that decreases outward to give a minimum C.C.E. of 60 percent for the measured volume. The carbonate is mainly tufa with minor amounts of marl.

The Epp deposit is a hillside-seepage (B-1) type, found on a wooded hillside. A single sample tested at 94 percent C.C.E., with the carbonate entirely as marl with a minor amount of coarse-grained tufa. The wedge-shaped deposit thins from about 1 m to 40 cm, 30 m downslope. If the deposit is 150 m long and 50 m wide (estimate), it may contain 3700 m^3 of good quality marl.

Both these deposits could be developed to provide agricultural lime; however, quarrying would be difficult due to wet conditions. Low volume is compensated for by high quality and easy access.

NORTH-CENTRAL ALBERTA

WHITECOURT (N.T.S. SHEET 83J)

Settlement in the Whitecourt area is confined primarily south and east of the Athabasca River and consists of flat to undulating glaciolacustrine and till plains (St. Onge, 1975). Exploration was confined to this southern area due to problems of access elsewhere within the map area (Fig. 2).

Three deposits and one showing were found (Table 9). Additional discoveries are possible, particularly in the western part of the region where the area is underlain by the Paskapoo Formation. Groundwater discharging from the calcite-cemented sandstone should provide excellent sites for marl deposition. These deposits will probably be of the spring-seepage type, which are difficult to locate. Exploration in the till and glaciolacustrine areas of the region did not reveal any potentially exploitable deposits.

Deposits 1 and 2 - McGregor and Underwood (N.T.S. 83J/3)

Two hillside-seepage deposits (B-1) are known in the Blue Ridge area; one at 4-14-59-10-W5, the

McGregor, and one at 6-9-59-10-W5, the Underwood (Table 9). Surficial geology of the deposits is shown in Figure 11. Regional groundwater seems to move from the western highlands, eastward. These highlands are composed of relatively thin drift (less than 15 m thick) overlying the Paskapoo Formation. The eastern lowlands are covered by 15 to 30 m of drift (Carlson and Green, 1977). Most aquifers in the region are in bedrock, at shallow depths, and are Ca^{+2}, Mg^{+2}, HCO_3^- in chemistry (Tokarsky, 1976). Several seepages and springs are found in the area, including seepages at the marl deposits, and probably mark discharge from local systems flowing from either the till-bedrock contact or from shallow bedrock aquifers.

The McGregor deposit was extensively sampled by the owner, I. McGregor, and D. Penney of Alberta Agriculture. Mr. McGregor has stockpiled a quantity of marl. The following information was supplied by D. Penney. The deposit ranges in thickness from 3.6 m at the center to 30 cm at the margin. Interbedded with the non-tufaceous marl are thin layers of peat. C.C.E. values are quite variable with most from 80 to 85 percent with the organic rich layers being 40 to 60 percent. A composite sample from

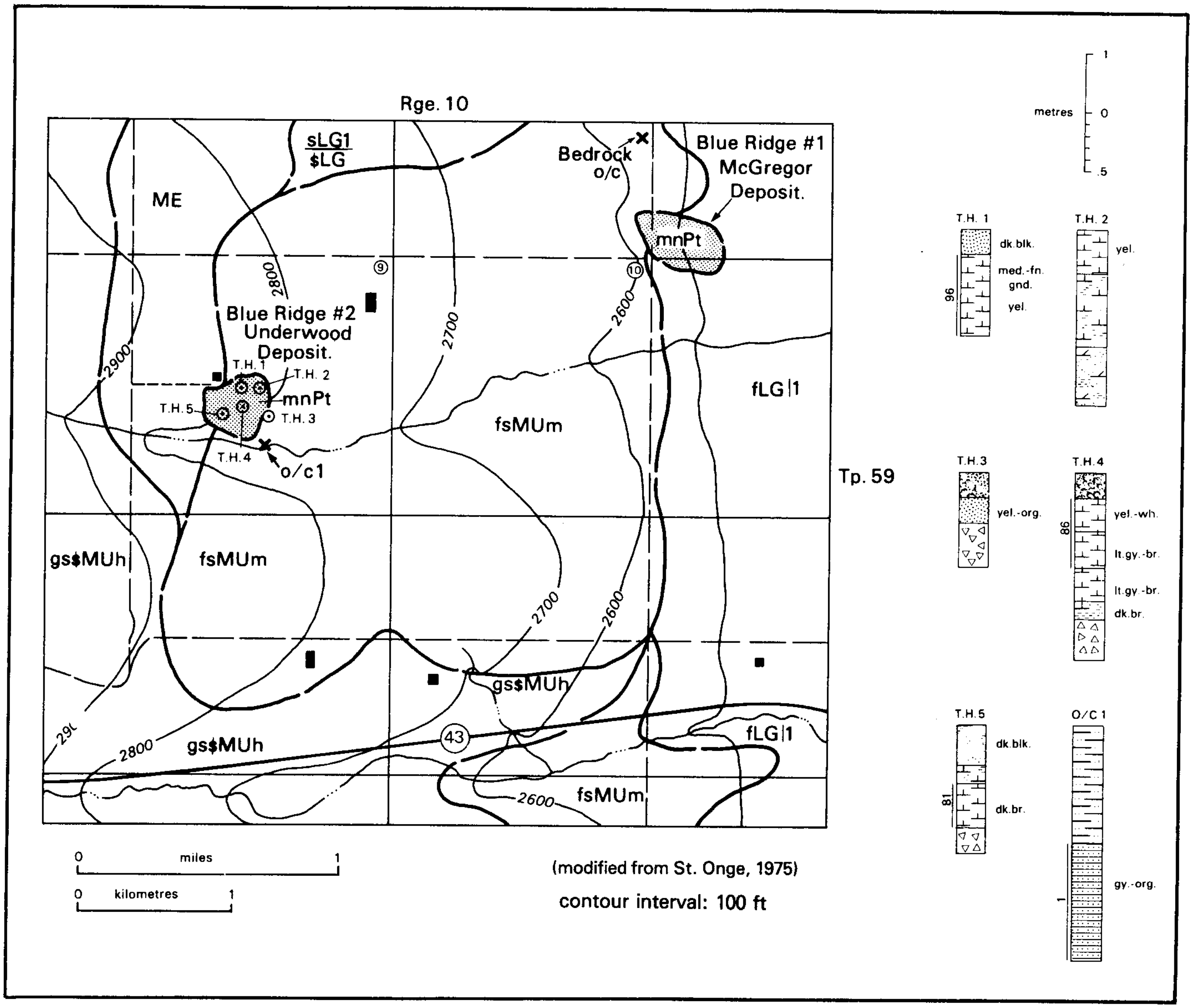


FIGURE 11. Surficial geology, testhole data and topography — Blue Ridge deposits

twenty locations in the stockpile showed an average C.C.E. of 77.5 percent. The stockpile contains an estimated 18 000 to 27 000 tonnes (20 000 to 30 000 short tons) of marl, calculated using a bulk density of 600 kg/m^3.

Examination of the Underwood deposit indicates an irregularly shaped body with a maximum thickness of 1 m. The C.C.E. values range from 81 to 96 percent for a non-tufaceous marl. D. Penney of Alberta Agriculture estimated the deposit to contain 9000 to 13 600 tonnes (10 000 to 15 000 short tons) of marl. Figure 11 shows deposit extent and testhole data.

Deposit 3 - Romeo Lake (N.T.S. 82J/2)

This group of shoreline fringe (C) deposits, approximately 36 km north of Sangudo (29, 30, 31-58-6-W5), are found around Romeo Lake on low-level benches that were submerged when the lake stood at a higher level (Fig. 12). Marl is not being deposited in the lake now. Relief in the area is less than 15 m and glacial drift is up to 20 m thick, but probably thins to 10 m at the lake. The drift consists of glaciolacustrine sediments overlying till that rest on Wapiti Formation sandstones and shales.

The approximate extent of the deposit is shown on Figure 12, based on aerial photo expression, surface

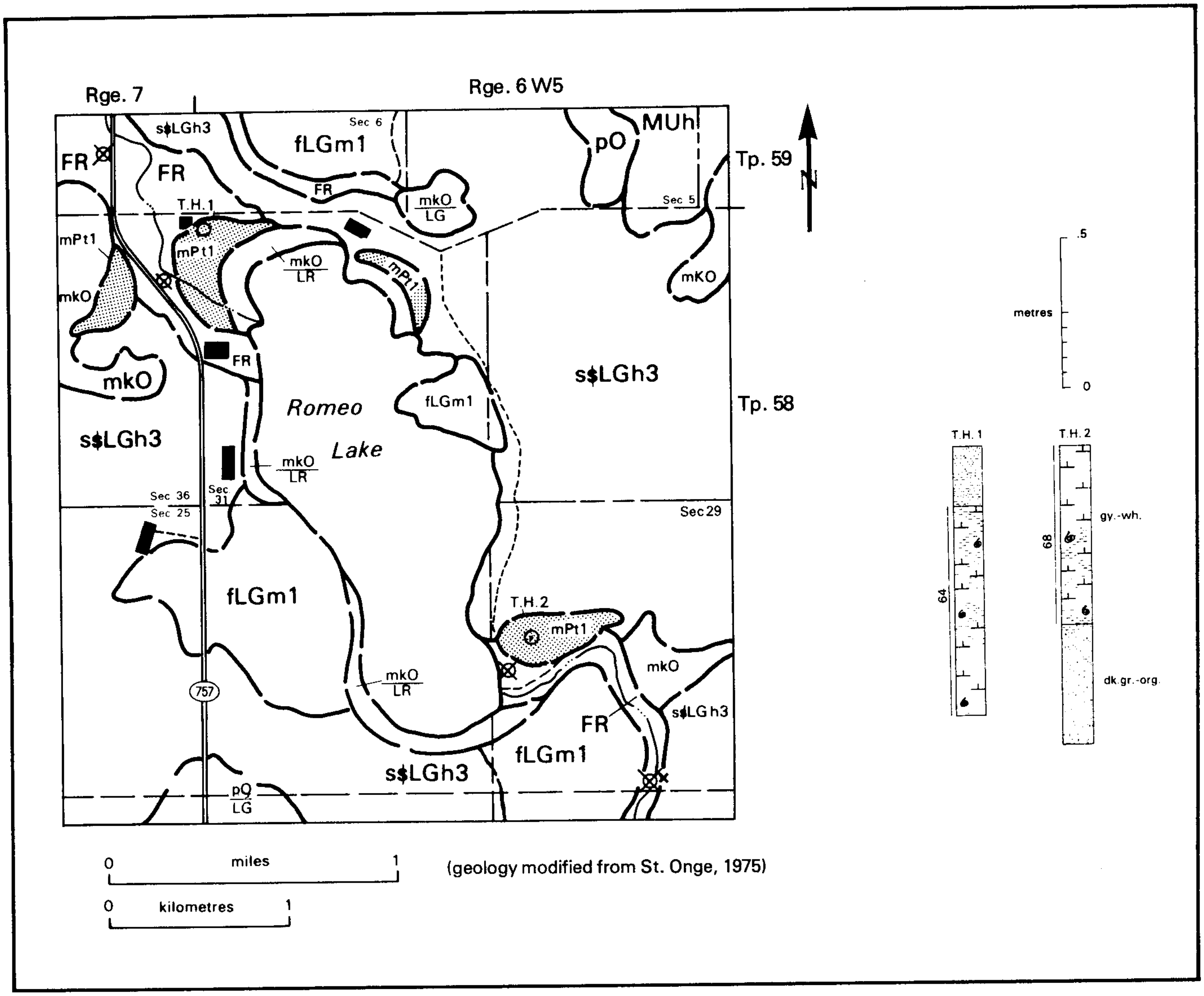


FIGURE 12. Surficial geology, testhole data, and access - Romeo Lake deposit

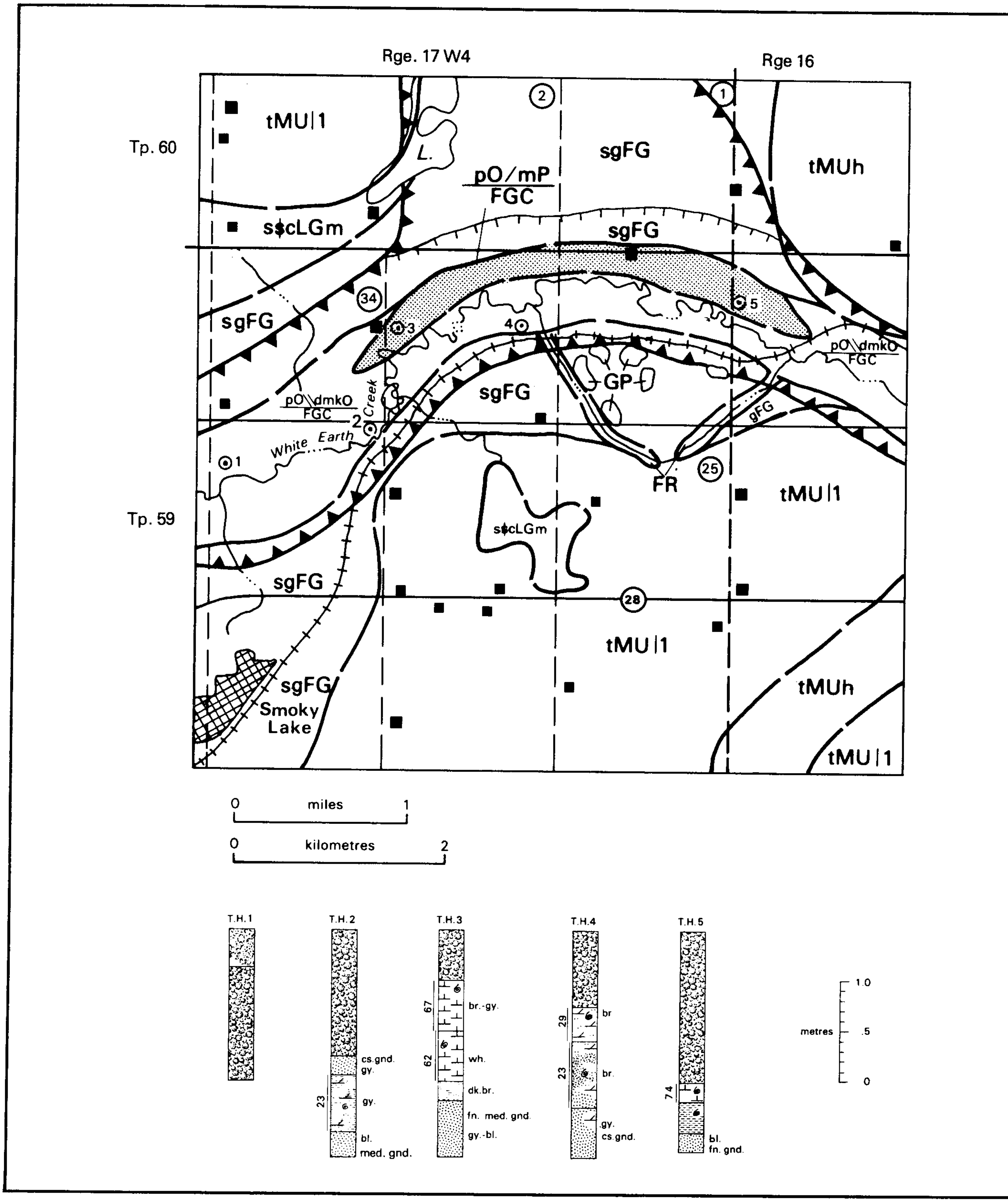


FIGURE 13. Surficial geology, testhole data, and access - Smoky Lake deposit

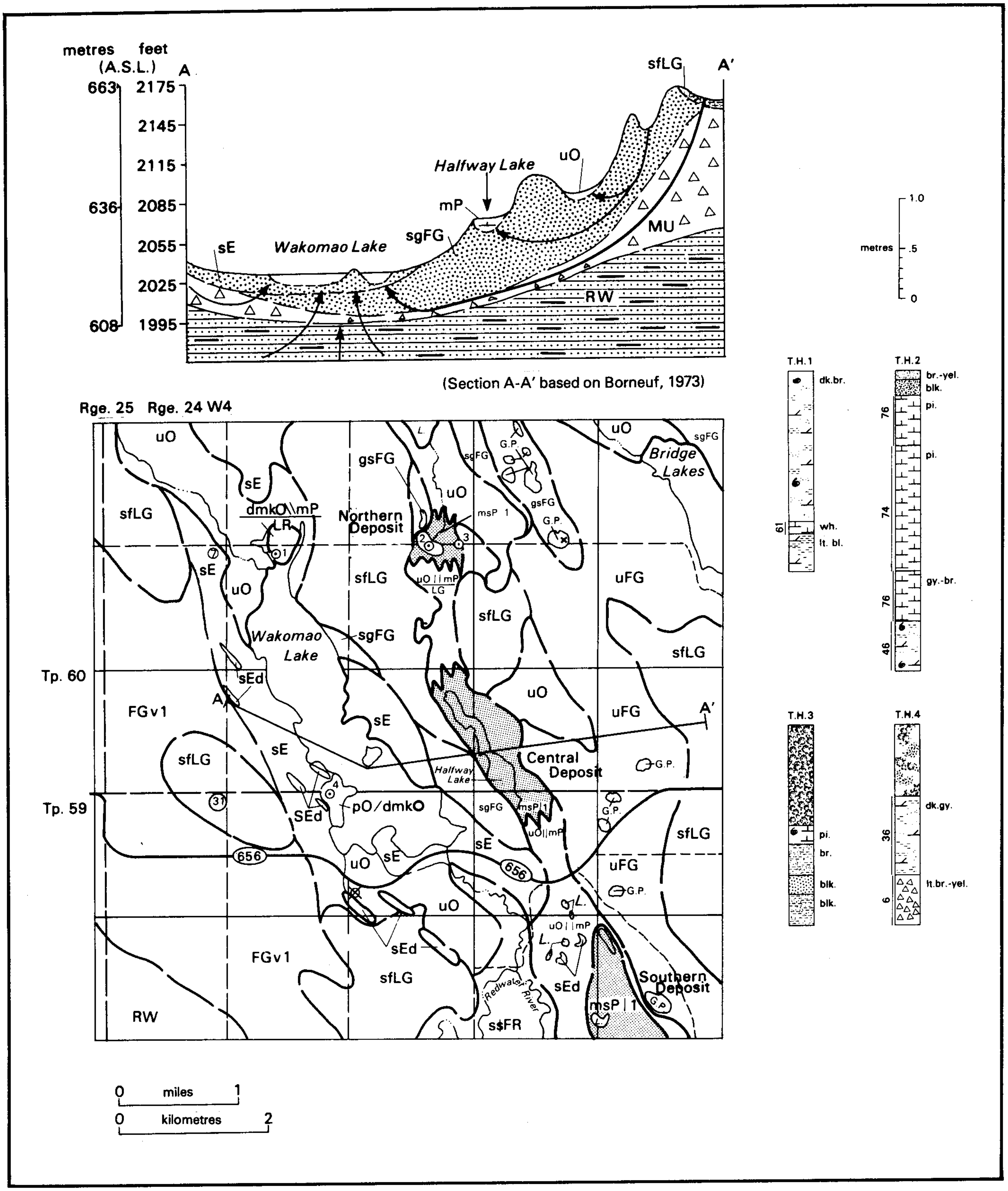


FIGURE 14. Surficial geology, testhole data, cross-section A-A', and access - Halfway Lake deposit

sightings, and a limited amount of sampling. Two testholes (Fig. 12) penetrated marl less than 1 m thick; however, owners of the deposit report thicknesses of 1.3 m at the southeast deposit. A sample from the southeast deposit contained about 65 percent C.C.E. with the major impurities as detrital quartz and less than 3 percent clay (Tables 10 and 11, Fig. 29). Microscopic examination revealed gastropods, numerous *Chara* seeds, ostracods, and plant remains.

With the limited data available, it was not possible to estimate the quantity of marl present. If quantities are adequate, however, the deposit is potentially usable for agricultural lime due to its dry setting, easy access, and friable, fine-grained nature. The low C.C.E. values could restrict use of the material.

TAWATINAW (N.T.S. SHEET 83I)

The map area is mostly settled and access is generally good throughout. Two large, inaccessible areas are in the central portion of the eastern half of the map sheet (Métis Colony No. 7) and the northwest corner. Exploration was confined to accessible areas.

Three deposits of which the best two are described, and one report of marl were found in this area (Table 9). The best area to explore further for marl is in the southern half of the area where a potential exists to find additional seepage-ponded (B-2) or abandoned, channel-glacial (D-1) deposits in outwash areas. Investigations of ground moraine, hummocky moraine, fine-grained glaciolacustrine deposits, and areas of exposed bedrock were unrewarding in that the rare deposits in these areas are very thin and of limited area.

Deposit 3 - Smoky Lake (N.T.S. 83I/1)

This deposit is found north and east of the town of Smoky Lake, along White Earth Creek (35, 36-59-17-W4) (Fig. 13). This class D-1 deposit is situated in the bottom of a broad, marshy meltwater channel that contains White Earth Creek. The surficial geology is shown in Figure 13. Drift in the channel is up to 15 m thick, but is absent in places. In the upland area, drift is about 45 m thick in most places (Carlson, 1977).

The main marl deposit consists of organic peat overlying marl, both of which overlie fluvial glacial channel sands (Fig. 13). The remaining sediments in the White Earth Creek valley show the same general stratigraphy; however, calcareous sediments replace the marl in the same stratigraphic position.

The two testholes (5 and 3, Fig. 13) intersected good quality marl with thicknesses of 0.2 and 1 m. C.C.E. values were 62 to 74 percent and the material was fairly dry, whereas samples from calcareous sediments in the valley contained 20 to 30 percent C.C.E. and were wet. Microscopic examination of a channel sample of good quality marl showed the material to be predominantly fine-grained calcite crystals with gastropods, octracods, and *Chara* sp. debris present. The primary contaminant is silica as detrital quartz or diatoms. Organic detritus is less than 7 percent and clay minerals are less than 3 percent (Tables 10 and 11, Fig. 29). The source of carbonate for marl precipitation is attributed to groundwaters with a Ca^{+2}, Mg^{+2}, Na^{+}, SO_4^{-2}, HCO_3^- chemistry (Borneuf, 1973) that discharge into the meltwater channel. Algae likely played a major role in marl precipitation.

Available information is inadequate to estimate the volume of marl present. The deposit, however, is probably large.

Deposit 4 - Halfway Lake (N.T.S. 83I/4)

The Halfway Lake deposits have been known for some time and in 1973 a plant was established by the Houg Cement Company to produce cement using the marl. The deposits are found 7 km east of the town of Clyde (3,4-60-24-W4).

The area is a broad lowland composed of mainly glaciofluvial and glaciolacustrine sediment (Fig. 14). These seepage-ponded deposits (B-2) are found north of, in, and south of Halfway Lake. The Houg Cement officials state the lake is spring fed. There is little surface drainage into the lake, and it is probably the discharge site for local groundwater flow from the highlands to the east (see flow lines, cross section Fig. 14). Samples from water wells completed in the drift on shallow bedrock in these highlands show the water to have Ca^{+2}, Mg^{+2}, HCO_3^- chemistry. Halfway Lake is shallow with a carbonate bottom (Plate 4) and marl precipitation, assisted by

Chara, is probably active there and in nearby smaller ponds. Vegetation growth is gradually filling in the ponds.

The northernmost of the three marl deposits is 1.3 km north of Halfway Lake (Fig. 14). Testhole 2 showed the marl to be the thickest and of highest quality at the center of the lake, where 225 cm of marl with a C.C.E. of 73 percent is present. The marl thins to 40 cm at testhole 3.

The material is predominantly crystalline calcite with *Chara* sp. seeds and stalks, ostracods, gastropods, and pelecypods. The major contaminant is mud (11 percent) of which less than one percent is clay minerals (Tables 10 and 11, Fig. 29), and organics (11 percent).

A size analysis of a sample from testhole 2 appears in Table 3. Marl is probably precipitating at present.

TABLE 3.
Grain size analysis of marls from major deposits in Alberta

Deposit	% Sand Size	% Silt Size	% Clay Size
Duffield	19.55	53.22	27.23
Halfway Lake	17.46	72.17	10.37
Lindbergh	11.98	45.74	42.28
Marlboro	11.29	39.17	49.54

Sand Size >.074 mm (200 mesh)
Silt Size <.074 mm to 4μm
Clay Size <5 μm

Information about the central and southern deposits was supplied by Houg Cement, which is currently mining the deposit. Limits of the central deposit are approximately those shown in Figure 14. Thickness of this deposit averages about 3 m. Most of the southern deposit is shown on Figure 14; however, it extends about 1.6 km southeastward beyond the area shown in the figure. Thickness of this deposit is variable ranging from 1 to 6 m. Quality for both deposits averages 72 percent C.C.E. (Holter, 1972).

The reserves at the northern deposit are estimated to be 126 000 m³ of 73 to 75 percent C.C.E. marl based on a thickness of 1 m over a radius of 200 m. Holter (1972) estimated 1 030 000 m³ of marl in the central deposit and 3 332 000 m³ in the southern deposit. These reserves would provide marl for 95 years of operation of the cement plant at an annual consumption of 112 500 tonnes (124 000 tons) of marl to produce 182 tonnes (200 tons) of cement a day.

Houg Cement is currently the only company in Canada using marl to produce cement. Because the deposits are very wet, the marl is mined by dragline during the winter when the surface is frozen. The marl is water saturated and must be stockpiled to drain and air dry, and finally must be artificially dried before use. Houg Cement officials are anxious to develop additional markets for their marl and have indicated a willingness to sell it for agricultural use.

Additional drilling and exploration for marl is warranted in the channel system in which the exploited deposits are found.

SAND RIVER (N.T.S. SHEET 73L)

This map area was only briefly investigated because it is remote from areas with problems of acidic soils. No deposits or showings of marl were found. Some Recent lake and bog sediments contained a calcareous matrix, but at none of the sites did the C.C.E. exceed 30 percent. The extensive till plains and lack of permeable surficial materials probably comprise an unfavorable setting for marl deposition. Future exploration should center around the outwash deposits in the Moose Lake area, to seek shoreline fringe or hillside seepage deposits.

WABAMUN (N.T.S. SHEET 83G)

Exploration was confined to the readily accessible portions of the area, which excludes the southwest quarter of the map sheet and the area north of Chip Lake. The land surface within the Wabamun area is rolling and covered primarily by till with lesser amounts of glaciolacustrine, glaciofluvial, and glaciodeltaic deposits (Andriashek *et al.*, 1979).

Six deposits, five showings, and six reports of marl are known from this area (Table 9). The two deposits having economic potential are discussed. The Wabamun map area has considerable potential for further marl discoveries for many reasons; including the presence of carbonate-cemented Paskapoo Formation bedrock aquifers, large areas of permeable surface sediments, high local relief, and a favorable climate (Appendix 1).

Future exploration should concentrate on areas listed as marl "Reports" and lakes, and bogs near contacts between deltaic and glaciolacustrine sediments. Ponds and bogs in which marl is currently being precipitated are readily identifiable on aerial photos because of the light-toned bottom sediments (Plate 3).

Deposit 2 - Evansburg (N.T.S. 83G/11)

This deposit, northwest of Evansburg (13, 14-24-54-8-W5), was reported by the present landowner, J. Tuttle. The deposit forms a boggy terrace on a wooded hillside. The highly alkali environment supports a sparse vegetation consisting of mosses, short grasses, and a few tamarack trees. Air photo expression is a very light-toned clearing on an otherwise heavily wooded hillside (Plate 2). Projection of an aquifer in the Paskapoo Formation, containing HCO_3^--rich waters, from 0.8 km to the north of the deposit suggests that discharge from this aquifer is depositing the marl. This is a hillside-seepage (B-1) deposit.

Eight testholes show that the deposit is thickest at the center of the terrace and pinches out a short distance away from it. Maximum thickness is 2.2 m at testhole 2.

C.C.E. values range between 48 and 93 percent with most above 70 percent. The carbonate material is mixed, sand-sized tufa clasts and marl. Analysis of a channel sample from testhole 2 shows quartz and organic matter to be the main contaminants (Tables 10 and 11, Fig. 29).

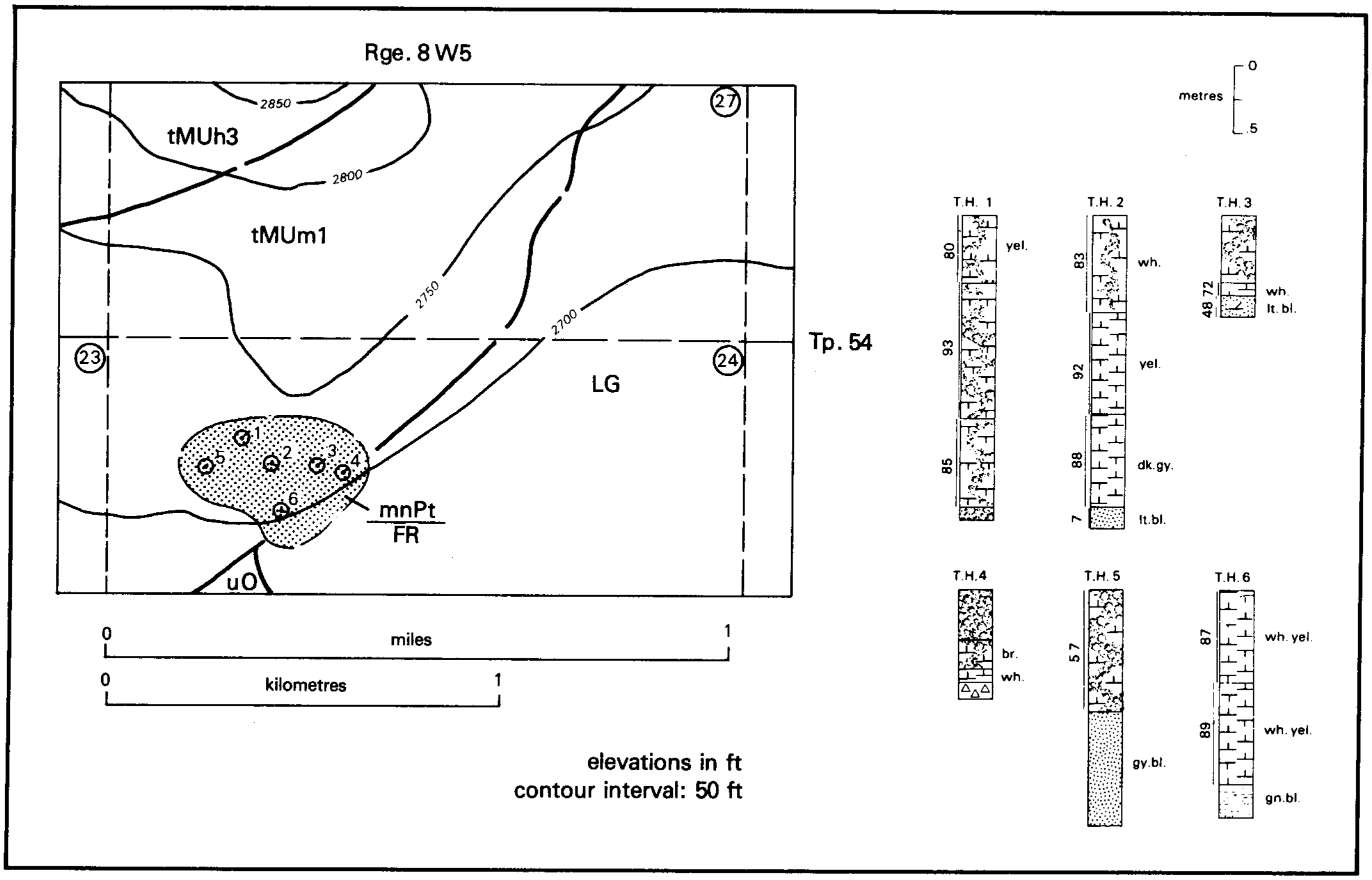


FIGURE 15. Surficial geology, testhole data, and access - Evansburg deposit

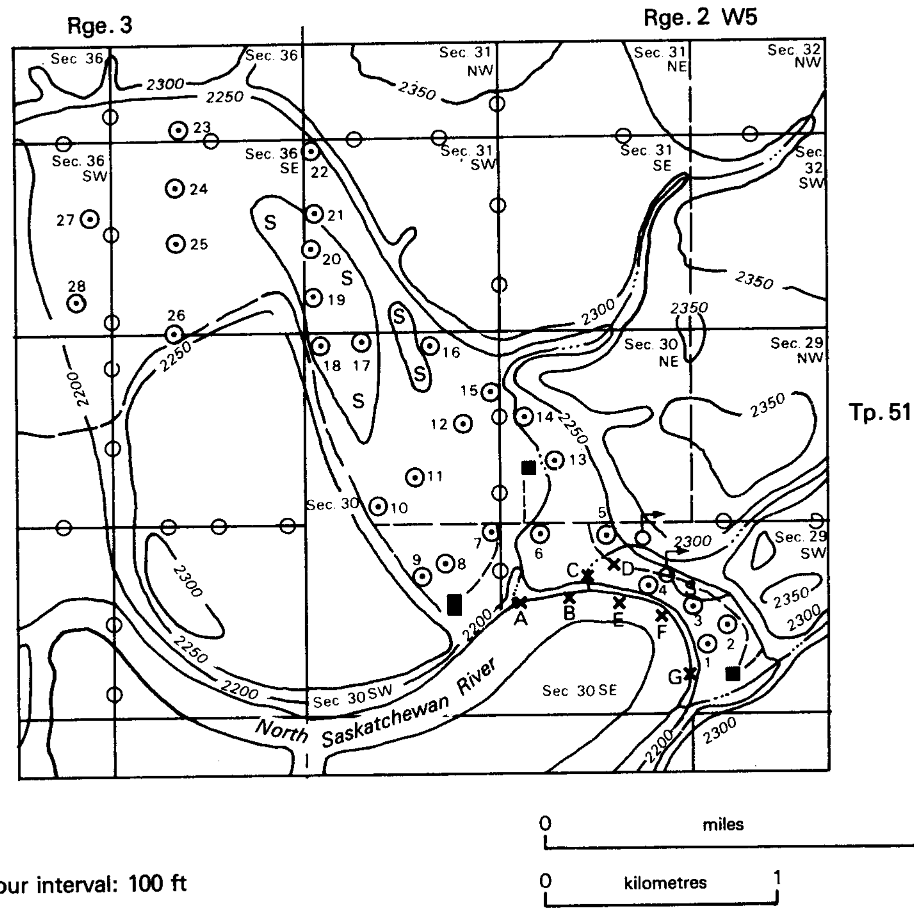


FIGURE 16. Topography and testhole locations - Duffield deposit

With the close spacing of the testholes, the volume estimate of 31 500 m³ (a body 1 m thick with a radius of 100 m) can be made with a high degree of confidence. This material has a C.C.E. of 73 to 93 percent and an additional volume of lower grade tufa is present. The deposit could potentially supply agricultural lime, with the main drawbacks being a high percentage of coarse material, a wet location, and need for a 300 m long access road.

Deposit 9 - Duffield (N.T.S. 83G/9)

This deposit was first described by Hillerud (1966) who studied the area in connection with fossil bison remains found in the marl. The deposit is near the North Saskatchewan River in an abandoned, filled in, oxbow lake (29, 30-51-2-W5 and 25, 36-51-3-W5). The valley bottom is dry and well drained except for minor groundwater seepages, and lies about 30 m below the surrounding upland and 3 m above the current river level (Fig. 16).

Surficial geology of the area is shown on Figure 17 (Plate 6). Drift in the highlands north and east of the deposit is up to 52 m thick. Waterwell logs indicate that a buried valley trending northeast passes under the marl deposit.

Groundwater discharge at the site is believed to be from shallow aquifers in the drift that contain Ca^{+2}, Mg^{+2}, HCO_3 rich waters rather than from the buried valley which contains Na^+, and SO_4^{-2} rich waters (A.R.C. - Groundwater files). According to Hillerud (1966), the marl was deposited in a clear, fresh water lake, with precipitation largely by the algae *Chara* sp. In many of the testholes, however,

PLATE 12. Duffield marl deposit, south end of deposit. North Saskatchewan River on left. Extensively slumped marl cliffs.

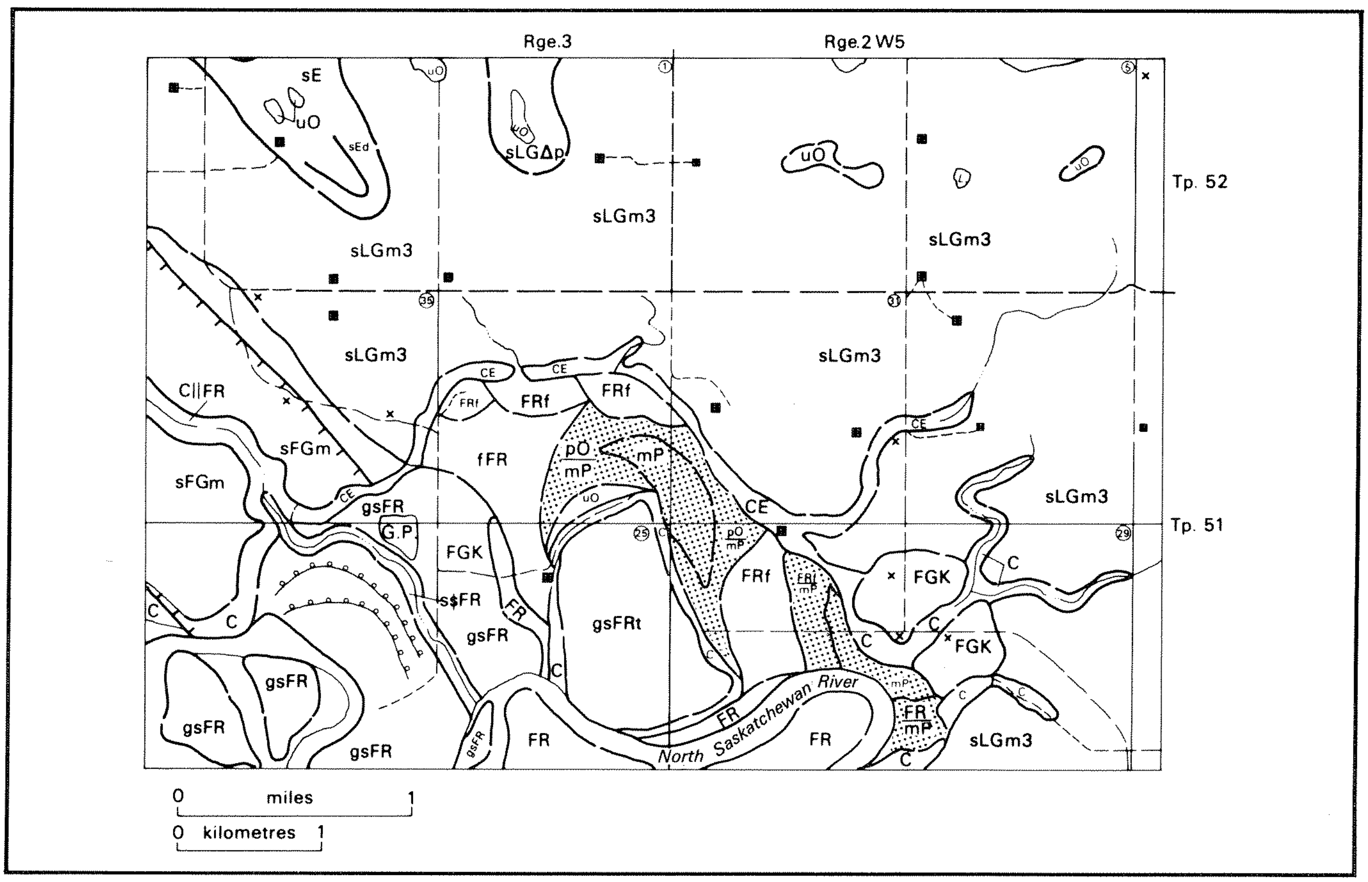
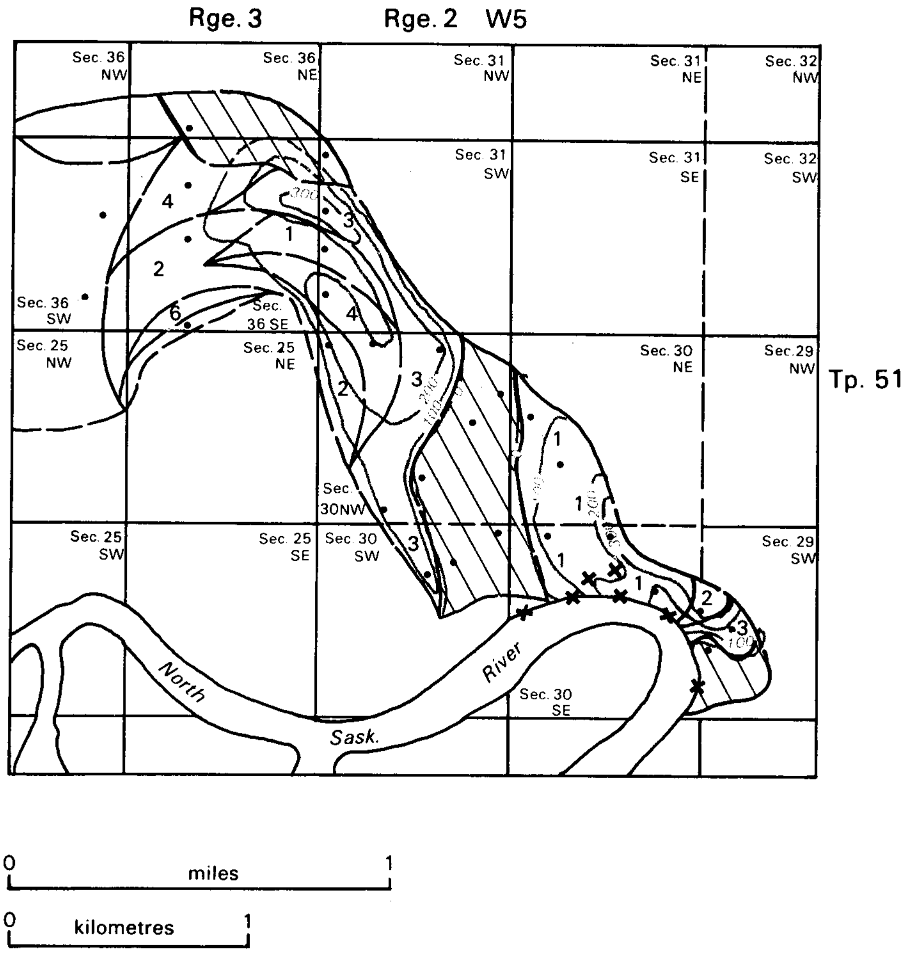


FIGURE 17. Duffield deposit area

TABLE 4.

Fossils in the Duffield marl

Testhole or O/C	Plant Frag.	Rock - frag.	Tufa	fn gn $CaCO_3$ (marl)	Chara sp "seeds"	Chara sp "stalks"	Ostracodes	Vertigo ovata	Stagnicola sp	Helisoma sp	Gyraulus sp	Promenetus exacuous	Valvata sp	Pisidium sp
2	numerous	X		X					X					
3	minor	minor	near bottom	X	X	X	X			X	X			
4			through out (fn. sd. size)	X					X					
5	minor	minor, only at bottom	through out (fn. sd. size)	X										
6	minor			X	X	X	X		X	X	X			
9	~20%	~20%		X	X	X	X			X			X	
10	~30%	~5%		X	X		X			X			X	X
13				X	X	X	X		X	X				
14	minor			X	X	X	X		X	X				
16	~10%	~5%	near bottom	X						X				
17	~20%	~10%		X	X	X	X	X	X	X		X	X	X
18	minor <5%			X	X					X	X		X	X
19	~20%	~20%		X	X		X		X		X	X		X
20					X	X	X			X				X
21	~15%	15%		X	X				X	X	X			X
24	20%	20%		X	X		X			X		X		
25				X	X		X		X	X				X
C	~10%		near bottom	X		X	X	X	X	X	X	X		
D	~5%	~5%	fn. sd. size	X			X	X						
E	~10%	~10%	X	X			X	X	X	X	X	X		
F			minor	X	X	X	X			X				X



- unknown area, marl likely present at depth (>1.4 m)

Marl Thickness (cm)

Contour Interval: 100 cm

• Testhole

Marl Grade Distribution
($CaCO_3$ equiv. dried Marl)

Zone	Grade Range %
1	80-99.5
2	70-79
3	60-69
4	48-59

FIGURE 18. Grade and thicknesses - Duffield deposit

tufa nodules at the base of the marl zone suggest physico-chemical precipitation in a subaerial environment for at least part of the deposition. Also algae remains are not abundant. Hillerud estimated the rate of deposition to be 4 mm/year.

Hillerud (1966) proposed the following history for the area. Following deglaciation, the North Saskatchewan River began cutting its new channel. The meandering river cut the wide valley where the site is found, deposited sand and gravel, and eventually abandoned the area forming the oxbow lake. Marl deposition began about 8000 years ago (based on a radiocarbon date of 8150 ± 100 years from a log at the base of the marl). Periodic flooding deposited fluvial clastic sediments within the accumulating marl. Plants gradually covered the lake to form a spruce bog and modern alluvium and slope wash eventually buried margins of the deposit. The North Saskatchewan River is currently eroding this site (Plate 12).

Samples from twenty-eight testholes and seven outcrops were examined (Fig. 16, Appendix 6). The thickness and grade of the marl are shown in Figure 18 and overburden thickness and composition of overburden are shown in Figures 19 and 17 respectively. In determining grade zones, low quality marl was considered overburden in some places. In addition to the reserves mapped, marl is likely present beneath 1 to 1.5 m of slope wash and alluvium in the portion of the channel in and adjacent to section 30

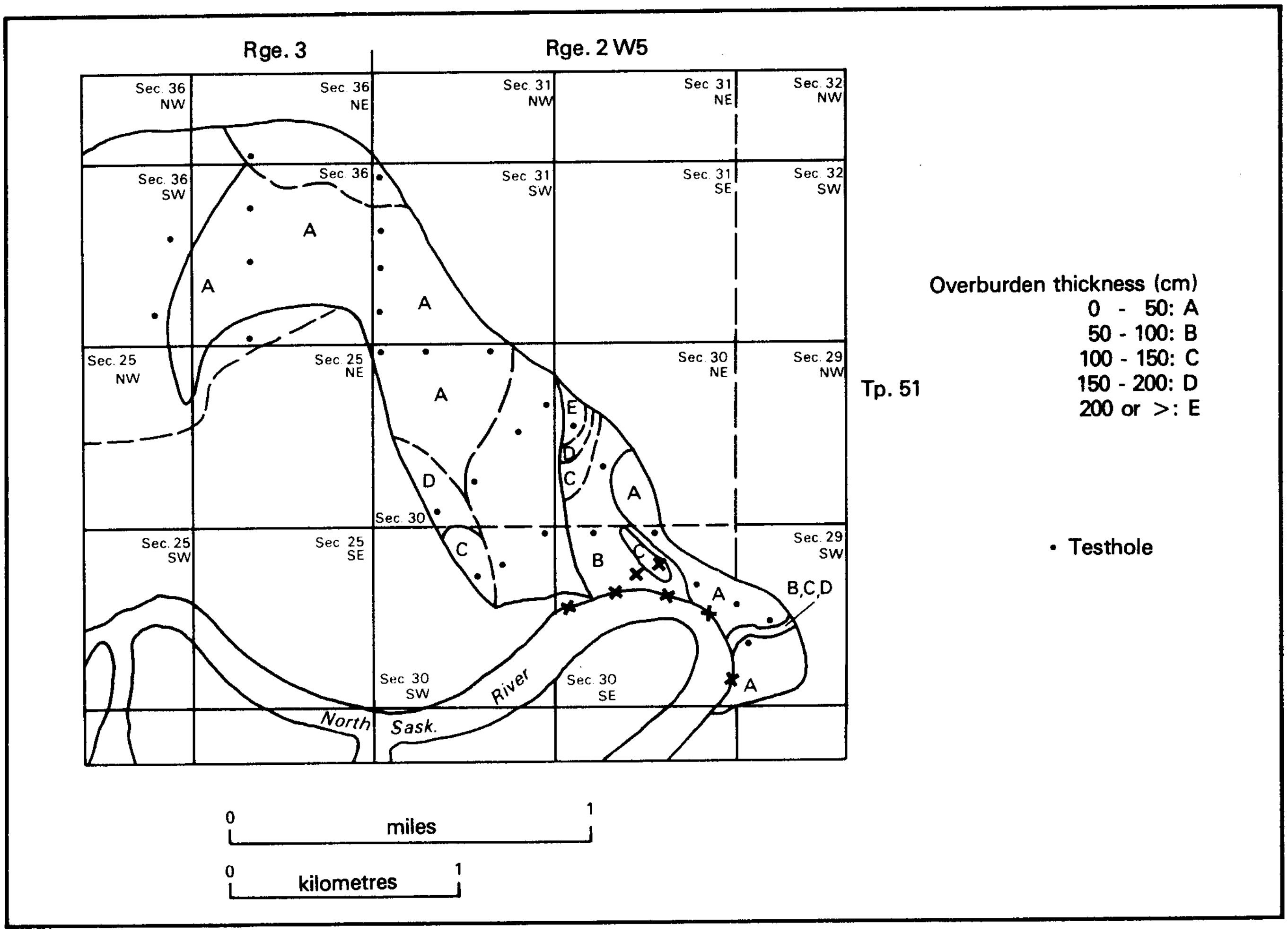


FIGURE 19. Overburden thicknesses - Duffield deposit

TABLE 5.
Reserve estimates of marl - Duffield deposit

W5 LOCATION	GRADE	AVERAGE THICKNESS (cm)	AREA (sq. m)	VOLUME (CUBIC METRES)	VOLUME (CUBIC YDS.)	LOCATION WET OR "DRY"
Twp. 51, Rge. 3,	1	100	35 076	35 076	45 879	W
Sec. 36, (SE, SW)	2	50	203 812	101 906	133 293	D
part of 25 (NW)	3	250	36 100	90 250	118 047	D
	4 North	50	108 300	54 150	70 828	W
	4 South	150	26 162	39 234	51 330	D
Twp. 51, Rge. 2,	1	100	50 086	50 086	65 512	W
Sec. 31 (SW)	2	200	4 977	9 954	13 020	W
	3	150	60 230	90 345	118 171	W/D
	4	200	40 259	80 518	105 318	W
Twp. 51, Rge. 2,	2	100	42 180	42 180	55 171	W/D
Sec 30 (NW)	3	150	132 430	198 645	259 828	D
	4	200	37 525	75 050	98 165	W
Twp. 51, Rge. 2 Sec. 30 (SW)	3	140	28 194	39 472	51 629	D
Twp. 51, Rge. 2, Sec. 30 (NE)	1	100	125 532	125 532	164 196	D
Twp. 51, Rge. 2,	1	150	150 575	225 863	295 429	D
Sec. 29 (SW)	2	300	16 066	48 198	63 043	D
and Sec. 30 (SE)	3	150	36 195	54 293	71 015	D

Grade 1. 80-99.5% C.C.E.
2. 70-79% C.C.E.
3. 60-69% C.C.E.
4. 48-59% C.C.E.

TOTALS	VOLUME (cu. m)	VOLUME (cu. yds.)
Grade 1	436 557	571 016
2	202 238	264 527
3	473 005	618 691
4	248 961	325 641

(Fig. 19). In general, the northern deposits show more variability in quality but less in overburden thickness than those in the south.

The results of microscopic examination of the samples are summarized in Table 4. Most of the calcium carbonate is marl, although nodular tufa fragments were found in outcrops C, D, E, and F as well as in testholes 3, 4, 5, and 16. X-ray diffraction and X-ray fluorescence analysis was performed on three channel samples of marl with the results shown in Table 10. The results show that marl from Grade Zone 1 (outcrop F and testhole 13) contain very little clay minerals. Chemical analyses of these samples (Table 11) show low amounts of SiO_2, K_20, and Al_2O_3.

The main contaminants are mud (<3 percent) and organic material (<3 percent). A bulk grain size analysis performed on the marl appears in Table 3.

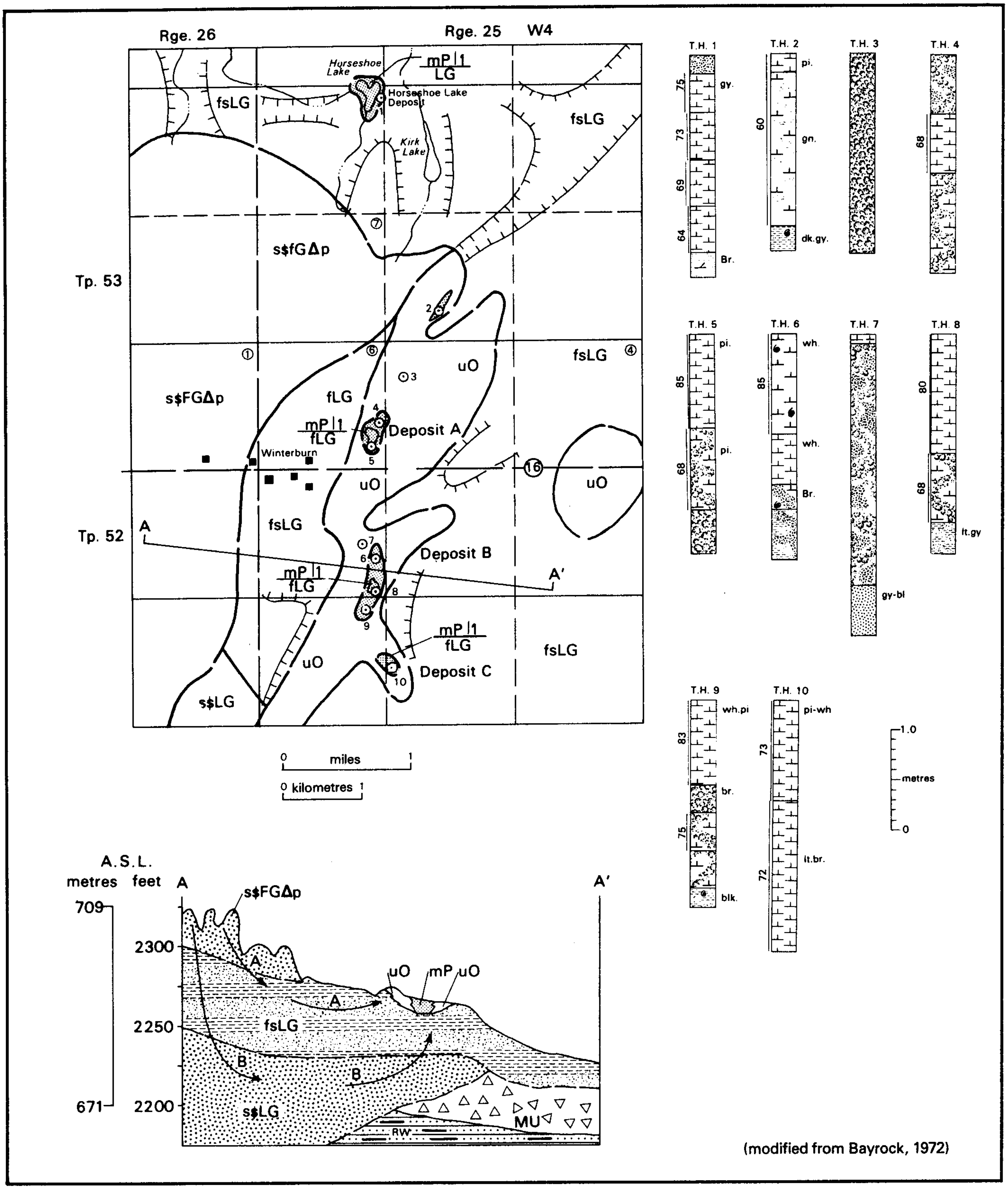


FIGURE 20. Surficial geology, testholes, location, and cross-section A-A' - Winterburn deposits

Most of the marl at this deposit falls in the pure marl class (Fig. 29). S.E.M. micrographs of the marl (outcrop F) show the calcite to be anhedral, flaky, generally <5μm in size and containing numerous diatoms.

The calculations of the amount of marl at this deposit were done according to the various grades within each quarter section (Table 5). This deposit has considerable potential for exploitation as a source of agricultural lime. Positive features are:

1. Large quantities and good grades.
2. Good access to most of the deposit.
3. Most of the deposit is dry enough to quarry.
4. Most of the calcium carbonate is as marl and not coarser-grained tufa.
5. Nearness to areas with acidic soils.

Drawbacks to the deposit are:

1. Some parts of it are water saturated.
2. In some areas, marl is mixed with peat and clastic detritus.

EDMONTON (N.T.S. SHEET 83H)

Of the eight deposits, five showings, and two reports in this area (Table 9), seven of the deposits have economic potential and are discussed. The Edmonton map area is well settled, has good access, and was extensively explored for marl. The eastern half, as well as the extreme northwestern and southwestern corners of the area, is low, gently rolling ground moraine. The west-central portion is covered with low to moderate relief glaciolacustrine deposits and dune deposits are found in the north-central and west-central parts of the area (Bayrock, 1972).

The Edmonton map area has considerable potential for the discovery of additional marl deposits. Exploration should concentrate on areas referred to as "Marl Reports" in this study and also along contacts between pitted deltaic and glaciolacustrine terrains. No marl was found in areas of ground moraine or hummocky moraine in the central and eastern parts of the area. Areas of fine-grained glaciolacustrine sediment were also devoid of marl deposits.

Deposits 1, 2, 3, and 4 - Winterburn area (N.T.S. 83H/12)

The Horseshoe Lake and deposits A, B, and C (Table 9, Fig. 20)[1] are all seepage-ponded deposits near Edmonton and found under similar settings. Since they have similar geology and settings, these deposits are discussed together.

All four deposits are in shallow, postglacial, meltwater channels that border the large, pitted delta area to the west. Deposits A, B, and C are found in calcareous bogs with small open pools of water whereas Horseshoe Lake is a shallow, clear, open lake. Groundwater discharge at the deposits is from the pitted deltaic sediments that contain Ca^{+2}, HCO_3^- bearing waters and are the primary aquifers of the region west of the deposits. The presence of groundwater flow through the pitted deltaic sediments is probably critical for the formation of these deposits (Fig. 20 - Cross Section A-A').

Horseshoe Lake: Testhole 1 (Fig. 20) showed nearly 2 m of water-saturated marl with a C.C.E. of 64 to 76 percent. *Chara* sp. seeds, ostracods, plant fragments, gastropods, and pelecypods are all present. Chemical analyses of the sample (Table 11) show the primary contaminants to be detrital quartz or diatoms (Fig. 29). X-ray diffraction and X-ray fluorescence results appear in Table 10. Based on an assumed average thickness of 1.5 m (testhole 1) and an area of 70 000 m^3, the inferred volume of marl is 105 000 m^3.

Deposit A: Testholes 4 and 5 (Fig. 20) penetrated 0.6 and 1.8 m of marl respectively with a C.C.E. ranging from 68 to 85 percent. Inferred reserves are 42 000 m^3 based on an area of 70 000 m^2 and an assumed thickness of 0.6 m over the entire deposit.

Deposit B: Three testholes (Fig. 20) indicate 150 to 190 cm of 68 to 85 percent C.C.E. marl. An assumed thickness of 1.5 m over an area of 200 000 m^2 gives inferred reserves of 300 000 m^3.

Deposit C: A single testhole (Fig. 20) penetrated 2.5 m of 72 to 73 percent C.C.E. marl. With an assumed average thickness of 1 m and an area of 36 000 m^2, a volume of 36 000 m^3 is inferred.

[1] See Table 9 for legal descriptions

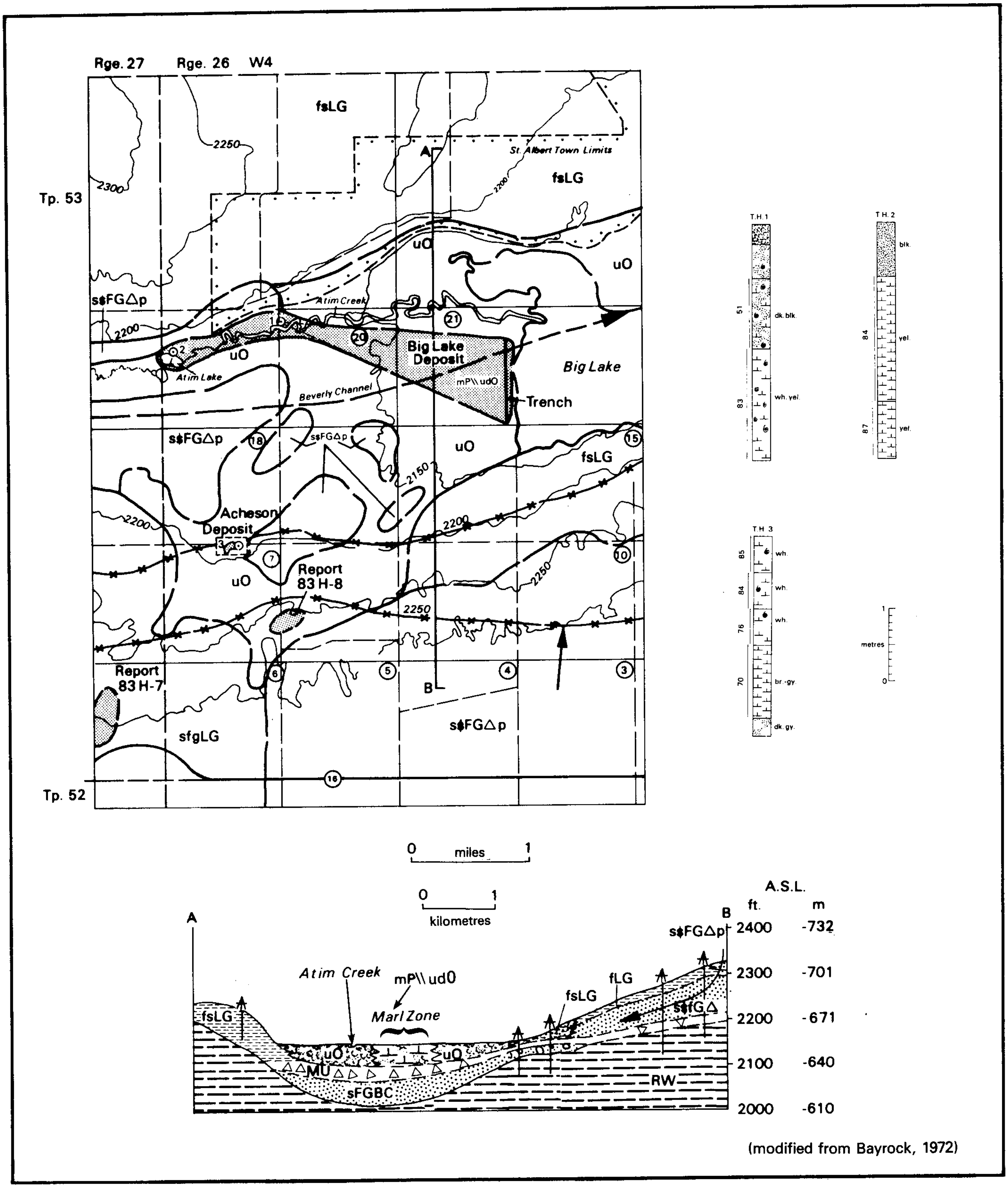


FIGURE 21. Surficial geology, testholes, locations, hydrogeology, and cross-section A-B - Big Lake area deposits

These reserves estimates yield a total volume for all four deposits of over 400 000 m^3, but are based on limited testhole data and should be considered tentative.

Land-use constraints imposed by proximity to the city of Edmonton may limit use of these deposits as may the fact that all four deposits are subaqueous. Other deposits of this type may be present in this area. Typically, these potential areas show as small, white-bottomed ponds within a spruce bog (Plate 3). The evolution of marl deposits of this type is discussed in Appendix 2. Interestingly, small ponds within the pitted delta area itself do not generally contain marl deposits, probably because these ponds are acting as recharge areas.

Deposit 5 - Big Lake and Vicinity (N.T.S. 83H/12)

A large, seepage-ponded (B-2) deposit of marl has been known at the west end of Big Lake since the early part of the twentieth century (19, 20, 21, 22, 27, 28, 29-53-26-W4, Fig. 21). This deposit is in a lowland occupied by Big Lake, Atim Creek and Lake, and Sturgeon River. The Beverly preglacial valley as defined by Carlson (1967) is situated beneath Big Lake. Section A-B (Fig. 21) illustrates the inferred stratigraphy and groundwater flow of the area. Groundwater moves through perched aquifers in glaciolacustrine and deltaic deposits south of Big Lake northward and into the lake. At a greater depth, groundwater flows into and along the buried Beverly channel.

Precipitation of the marl is largely attributed to *Chara* sp. algae with calcified algal material making up nearly 100 percent of the marl at Atim Lake (Plate 11) and nearly 90 percent of the material in Big Lake. A mature freshwater fauna of ostracods, gastropods, and pelecypods was identified by Drake (1970) at Big Lake. Chemical analyses reveal quartz and clay minerals to be the major contaminants (Table 11, Fig. 29). X-ray diffraction and X-ray fluorescence determinations from testhole 2 appear in Table 10.

Marl with an average thickness of 1 m is exposed in a trench for a distance of 1200 m across the Big Lake deposit (Fig. 21). The testhole at Atim Creek (testhole 1) penetrated 1.5 m of marl and, if the deposit is continuous between Atim Creek and the test trench, a volume of 1 920 000 m^3 of marl with a C.C.E. of 50 to 82 percent is present.

The testhole at Atim Lake encountered 250 cm of marl with a C.C.E. of 84 percent and suggests that the Big Lake deposit may extend westward, along Atim Creek to Atim Lake. This extension would represent 656 000 m^3 of marl assuming a thickness of 1.5 m. The total volume of marl in the Atim-Big Lake deposit is approximately 2 575 000 m^3 of water-saturated marl with a C.C.E. of 50 to 82 percent.[1]

The Big Lake marl deposit was once considered a source of raw material for cement manufacture. Objections from the standpoint of wildlife and water management have, however, curtailed development of the deposit.

Deposit 11 - Spruce Grove (N.T.S. 83H/12)

This seepage-ponded (B-2) deposit is located north of Spruce Grove, Alberta (1-29-53-27-W4, Fig. 22). The marl is deposited on the bottom of small ponds at the base of a highland area to the north.

The origin of the deposit is interpreted to be the result of precipitation from Ca^{+2} and HCO_3^- bearing waters that move through permeable glaciolacustrine sands and discharge at a contact with impermeable silts and clays.

These marls range from 68 to 84 percent C.C.E. with the primary contaminant being organic detritus (Fig. 29). Clays are not present in significant quantities and at testhole 5, the sandiest portion of the deposit, detrital quartz is less than 2 percent of the marl. Complete testhole data appear in Figure 22. X-ray diffraction, X-ray fluorescence, and chemical analysis from marl at testhole 5 appear in Tables 10 and 11.

Approximately 20 000 m^3 of marl are present with an average thickness of 1 m and a minimum C.C.E. of 68 percent. This deposit has good potential for use as liming material: large quantity of good quality, readily accessible, and non-tufaceous. The wet

[1] A detailed study of the Big Lake area deposits was undertaken in the past by a private company. Details are not reproducible but the results indicate that the assumptions made in this report are valid and the estimated reserves are very conservative.

location and closeness to acreage subdivisions would adversely affect its use.

Deposit 15 - Bon Accord (N.T.S. 83H/14)

Two abandoned channel (D-1) deposits north of the town of Bon Accord (12-57-24-W4, northern deposit and NE 31-56-23-W4, southern deposit) are found in a wide valley 20 m deep that is marshy at the northern deposit and is filled by a shallow lake at the southern deposit.

The channel is incised into pitted deltaic sediments (Fig. 23 and Section B-B', Fig. 24). R. Stein (pers. comm.) has suggested that perched groundwater containing Ca^{+2}, Na^{+}, HCO_3^- and SO_4 is probably moving laterally through the deltaic sediments along the channel (Fig. 24, Section B-B'). Upon discharging at the surface, marl is precipitated, probably aided by *Chara* sp.

Thirteen testholes were drilled in the two deposits (Fig. 23 and Appendix 7). Section A-A' (Fig. 24) shows the interfingering of the facies and how the grade of marl varies along the channel. The marl is water saturated and contains abundant fossils and Chara fragments. The major contaminants are silica, up to 9 percent, and organic matter, with clays present in trace quantities (Tables 10 and 11 and Fig. 29).

Bon Accord (north deposit): Assuming a thickness of 1 m and a minimum grade of 65 percent C.C.E., a volume of 392 600 m^3 of marl is present. If a 50 percent C.C.E. value is accepted, the thickness available is 1.5 m, which increases the volume to 589 000 m^3.

Bon Accord (south deposit): Variability of thickness makes estimating volume difficult. It is assumed that a minimum volume of 72 600 m^3 of 50 percent

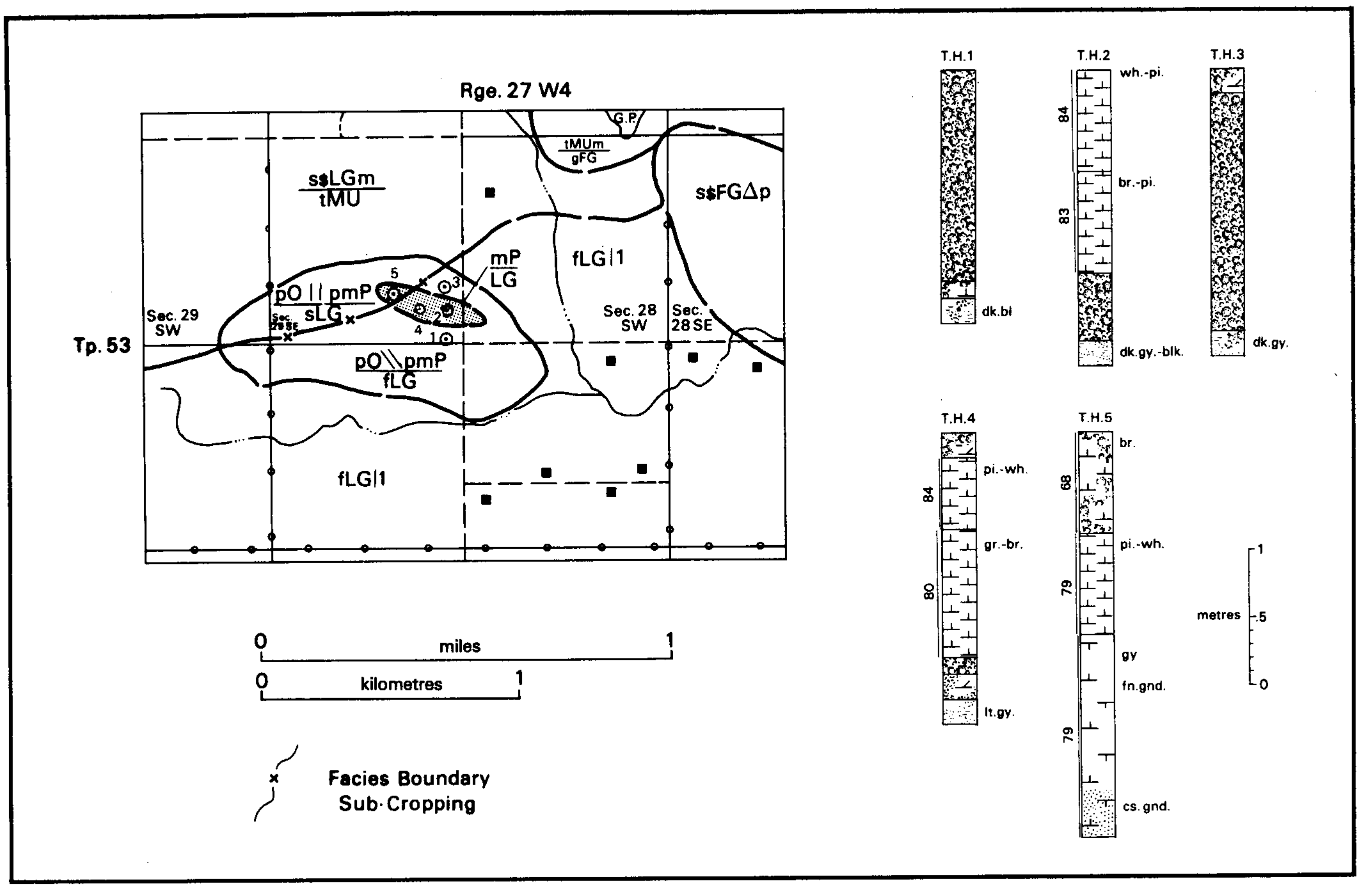


FIGURE 22. Surficial geology, location, and testhole data - Spruce Grove deposit

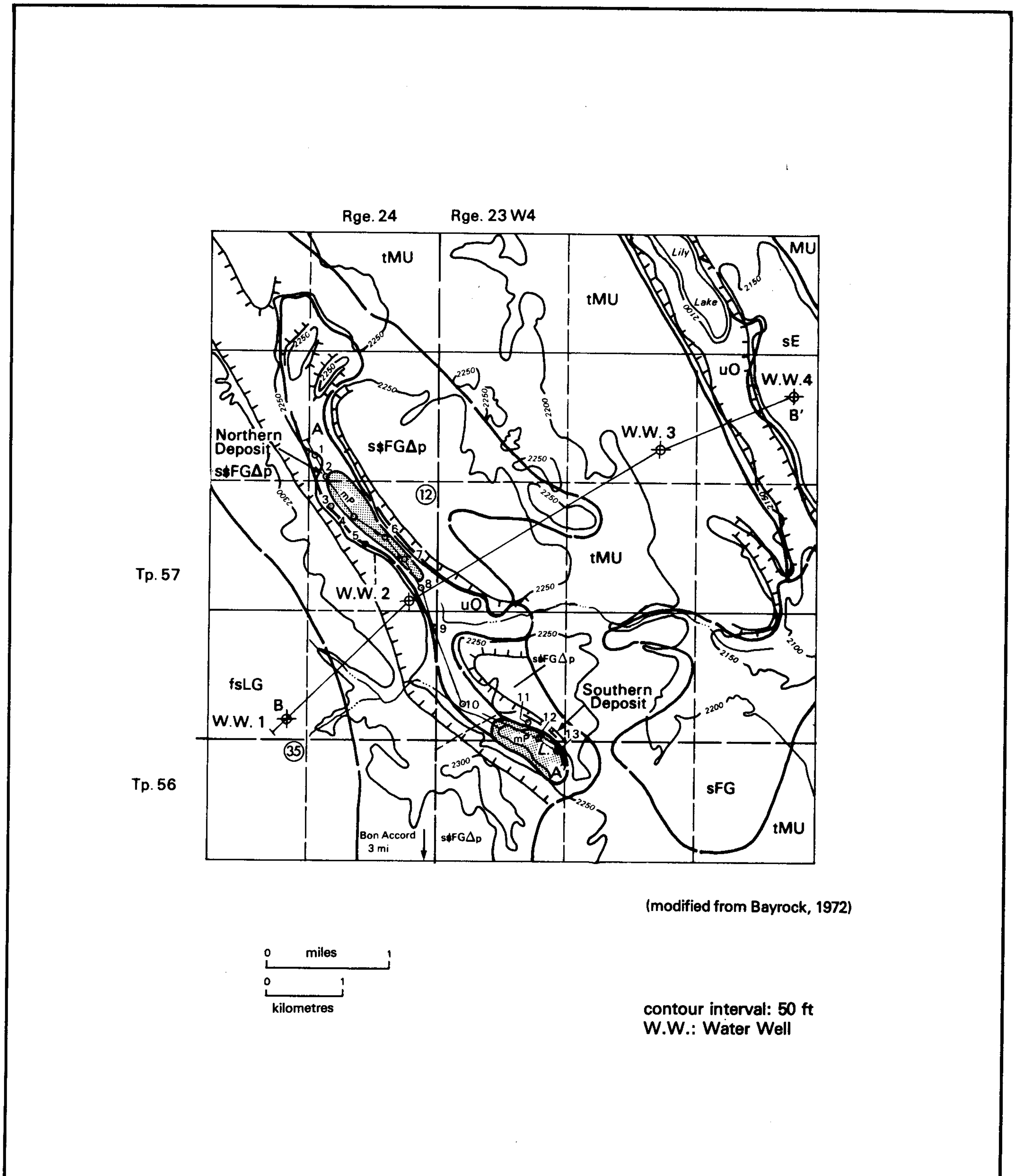


FIGURE 23. Surficial geology, topography, testhole locations, and access - Bon Accord deposits

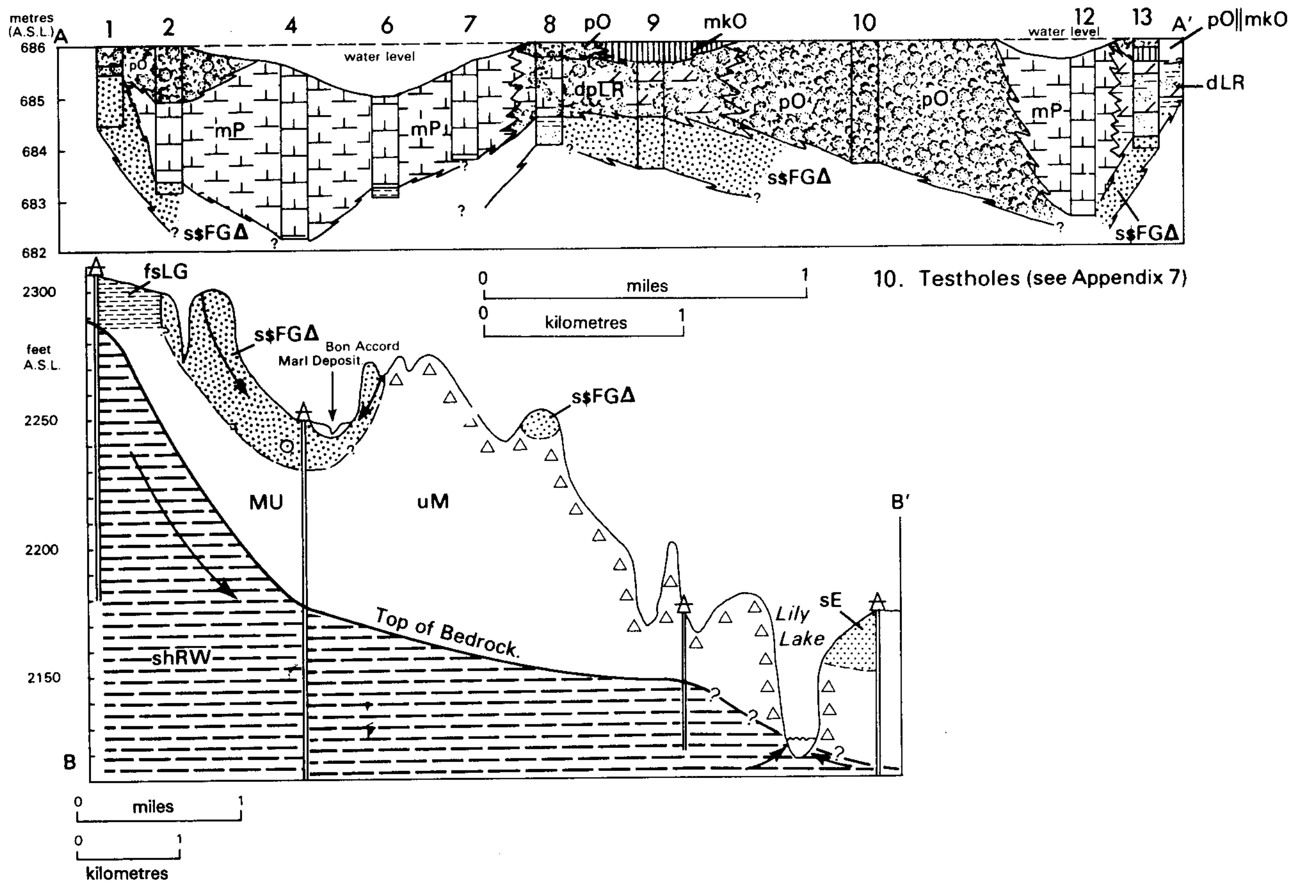


FIGURE 24. Cross-section B-B′ longitudinal section A-A′ - Bon Accord deposits

C.C.E. marl is present as a layer of 1 m thick with a radius of 152 m.

With a total volume of 50 percent C.C.E. marl of 661 500 m^3, these deposits are a potential source of agricultural lime. The deposits contain friable marl, are readily accessible by road, and are near areas of acid soils. The marl is covered by at least 1 m of water, so extraction would be difficult.

VERMILION (N.T.S. SHEET 73E)

Two deposits and two showings of marl were found in this map area (Table 9). The area is, in general, an undulating to rolling plain. Road access is good except in the northeast corner.

The surficial geology of the area is mainly undulating ground moraine and rolling hummocky moraine. Glaciofluvial deposits are found along scattered meltwater channels, particularly along the North Saskatchewan River from Elk Point to Lea Park and the Vermilion River near the Vermilion townsite (Ellwood, 1961). With approximately 90 percent of the area covered by low permeability till or glaciolacustrine deposits, the potential for additional marl deposits is low.

Deposit 1 - Lake Brosseau (N.T.S. 73E/13)

Marl was discovered at two locations at Lake Brosseau north of Two Hills, Alberta at the northwest and southwest bays of the lake (14, 23-56-12-W4), in subaqueous settings. These are shoreline fringe (C) deposits precipitated from groundwater flowing from thin sandy drift that overlies and is interbedded with till in the region (Fig. 25). Physico-chemical

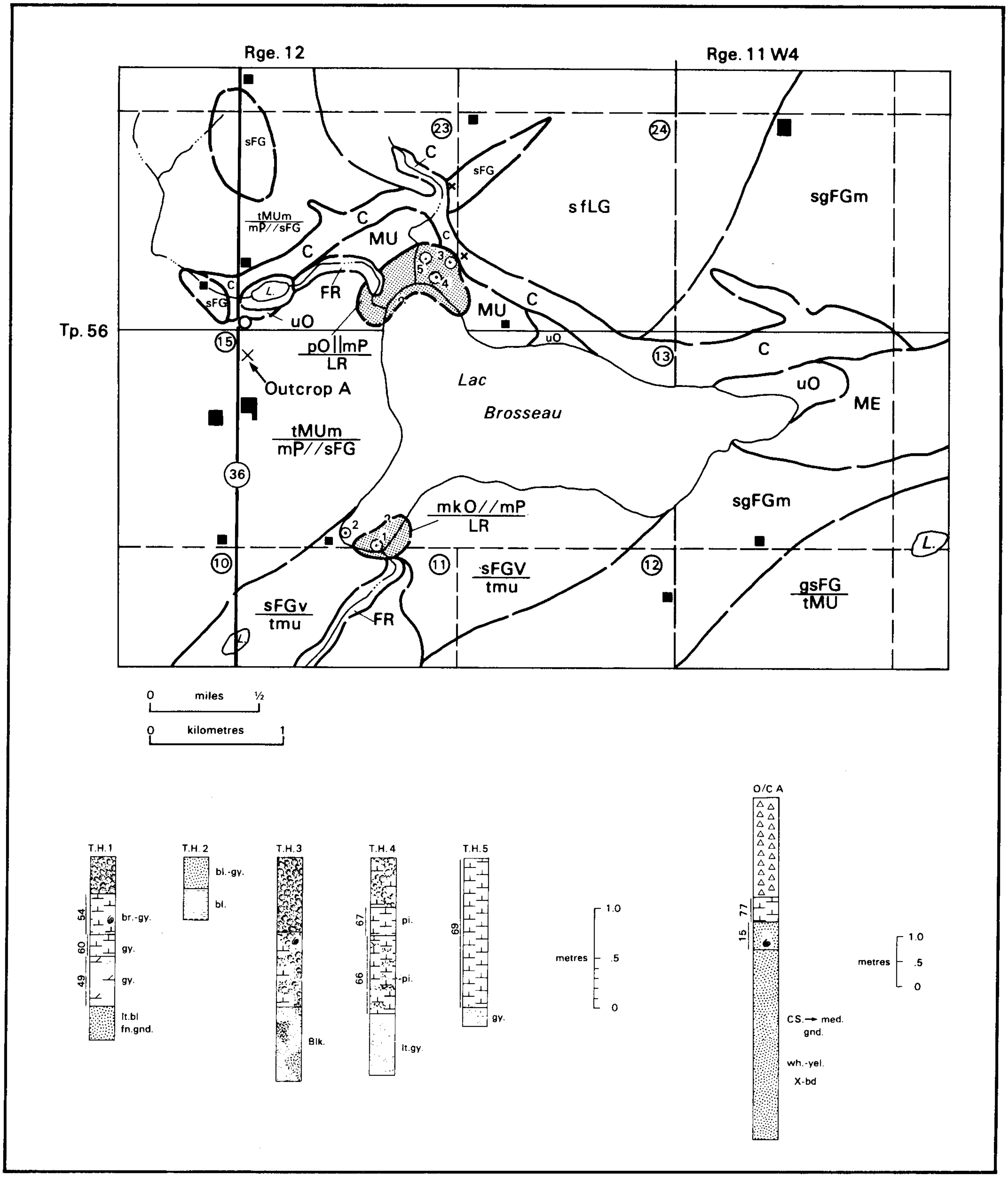


FIGURE 25. Surficial geology, location, and testhole data - Lac Brosseau deposits

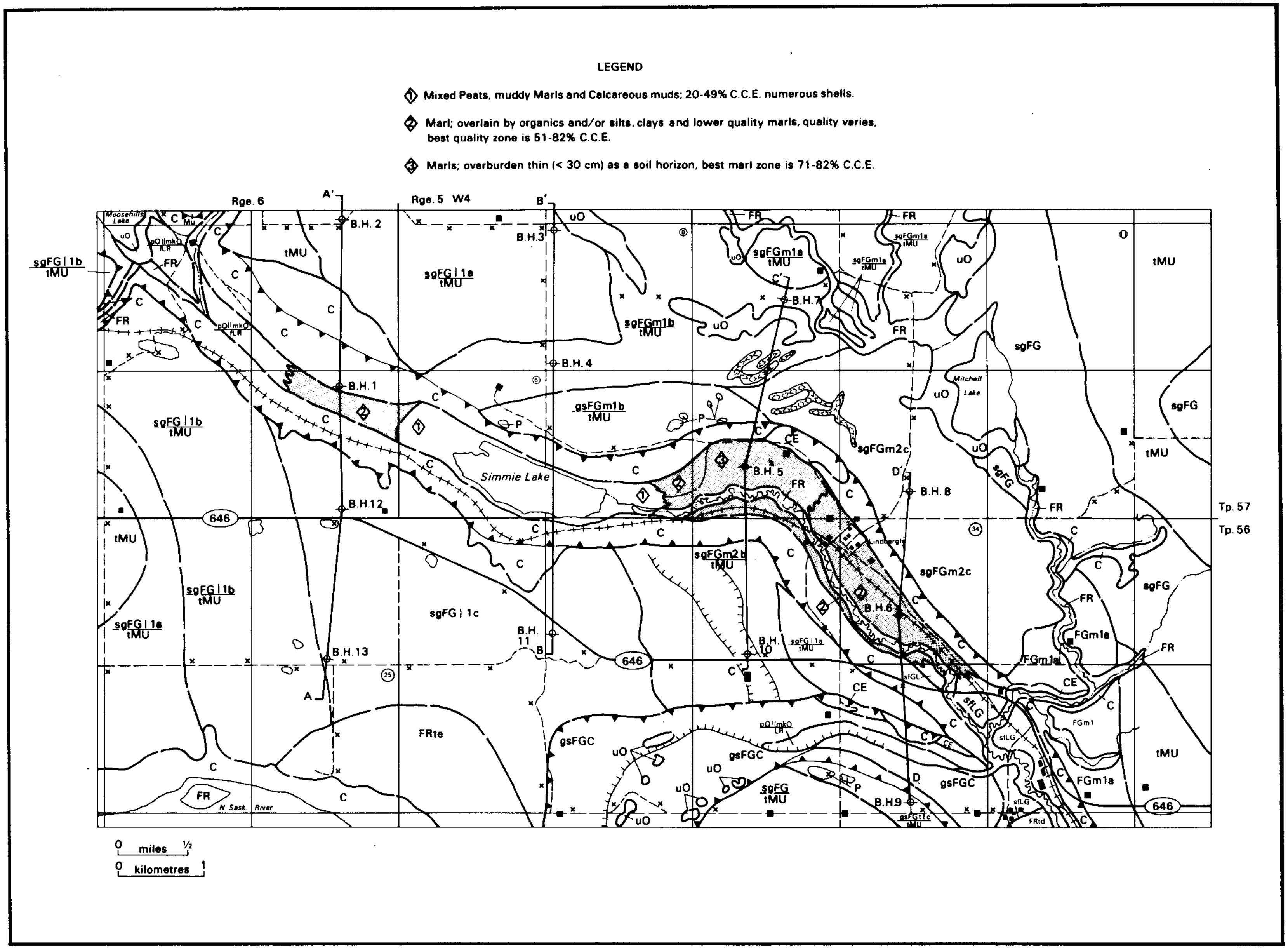


FIGURE 26. Surficial geology, location, access, and cross-section locations - Lindbergh deposit and vicinity

processes appear to have been dominant in controlling precipitation. Marl observed in outcrop A (Fig. 25), probably represents a small interglacial lake that developed before the last till was deposited and is a preglacial (H-1) deposit.

Four testholes encountered non-tufaceous marl at the two deposits (Fig. 25). The sediments at testhole 1 (southwest deposit) are 110 cm thick, with C.C.E. values of over 48 percent. Marl at the northwest deposit was generally of better quality (>66 percent C.C.E.) and of approximately the same thickness. Peat and organic deposits overlie the marl in most places. Analysis of a sample from testhole 4 (Tables 10 and 11, Fig. 29) shows the material to be pure marl with less than 10 percent quartz and almost no clay.

With the limited data available, the quantity of marl in the southern deposit cannot be estimated. In the northern deposit, the distance from testhole 4 to 5 (160 m) is assumed to be the diameter of a tabular marl body with a thickness of 110 cm and a minimum quality of 66 percent C.C.E. This assumption results in a volume of 22 000 m^3 with an overburden of 0 to 50 cm.

Additional work is required to assess the suitability of these deposits for agricultural lime.

Deposit 2 - Lindburgh (N.T.S. 73E/15)

The deposit is in the wide, flat-bottomed, Simmie Lake meltwater channel, which is incised about 65 m into an area of predominantly glaciofluvial outwash. The setting and geology of this abandoned channel-glacial (D-1) deposit are shown in Figures 26 and 27 and Appendix 9. Groundwater flow is from the highland areas north and south of the Simmie Lake channel into the channel where springs are present (Fig. 27 - cross-sections). The spring waters are Ca^{+2}, Mg^{+2}, HCO_3^-. The groundwater leaches carbonate from the surrounding areas of glaciofluvial outwash and underlying calcareous till. Marl precipitation does not appear to be active at present except near testhole 7 where calcareous mud overlies peat and topsoil. This suggests that *Chara* sp. algae may not have played an important role in the precipitation of the marl.

A total of 20 shallow testholes were bored in the Simmie Lake meltwater channel to define the extent and quality of marl deposits (Fig. 28, Appendix 8). The near surface sediments along the Simmie Lake channel show a considerable degree of lithologic variability and variation in C.C.E. content (Fig. 28 - Section E-E').

In Figure 28, the ratio of overburden thickness to marl thickness is shown for each testhole. Marl thicknesses ranged from 60 to 190 cm for geologic units 2 and 3, the marl units. The highest grade of marl is in the south half of 4-57-5-W4. In testholes 1 to 11, the marl lies below the water table, whereas in the remainder of the holes, the marl is dry and well drained.

Fossils from testholes 4, 11, 13, and 16 (Table 6) indicate that the paleo-environment of deposition was in a predominantly deep, cool, permanent body of water (Drake, 1970). The calcium carbonate is entirely as marl, with most finer than sand (Table 3).

Analyses of the samples (Tables 10 and 11) indicate the major contaminants of the marls to be SiO_2 as quartz or diatoms, clay minerals (less than 3 percent), and organic detritus. Composition is shown in a ternary diagram, Figure 29.

TABLE 6.
Fossils in the Lindbergh marl

	Testhole				
Fossils	2	4	11	13	16
Gastropods					
Valvata tricarinata	P	P	P	PA	
Gyraulus sp	P	P	P	PA	P
Helisoma sp	P	P	P		P
Oxytoma retusa	P				
Vertigo sp					P
Valvata lewisi			P		
Promentus exacuous	P	P	P		
Physa sp			P		
Pelecypods					
Pisidium sp	P	P			
Spherium nitidium		P			
Chara sp remains					
"stalks"		P	P	P	P
"seeds"	P	P	P	P	P
Ostracodes	P	P	P		

P - present
PA - present and abundant

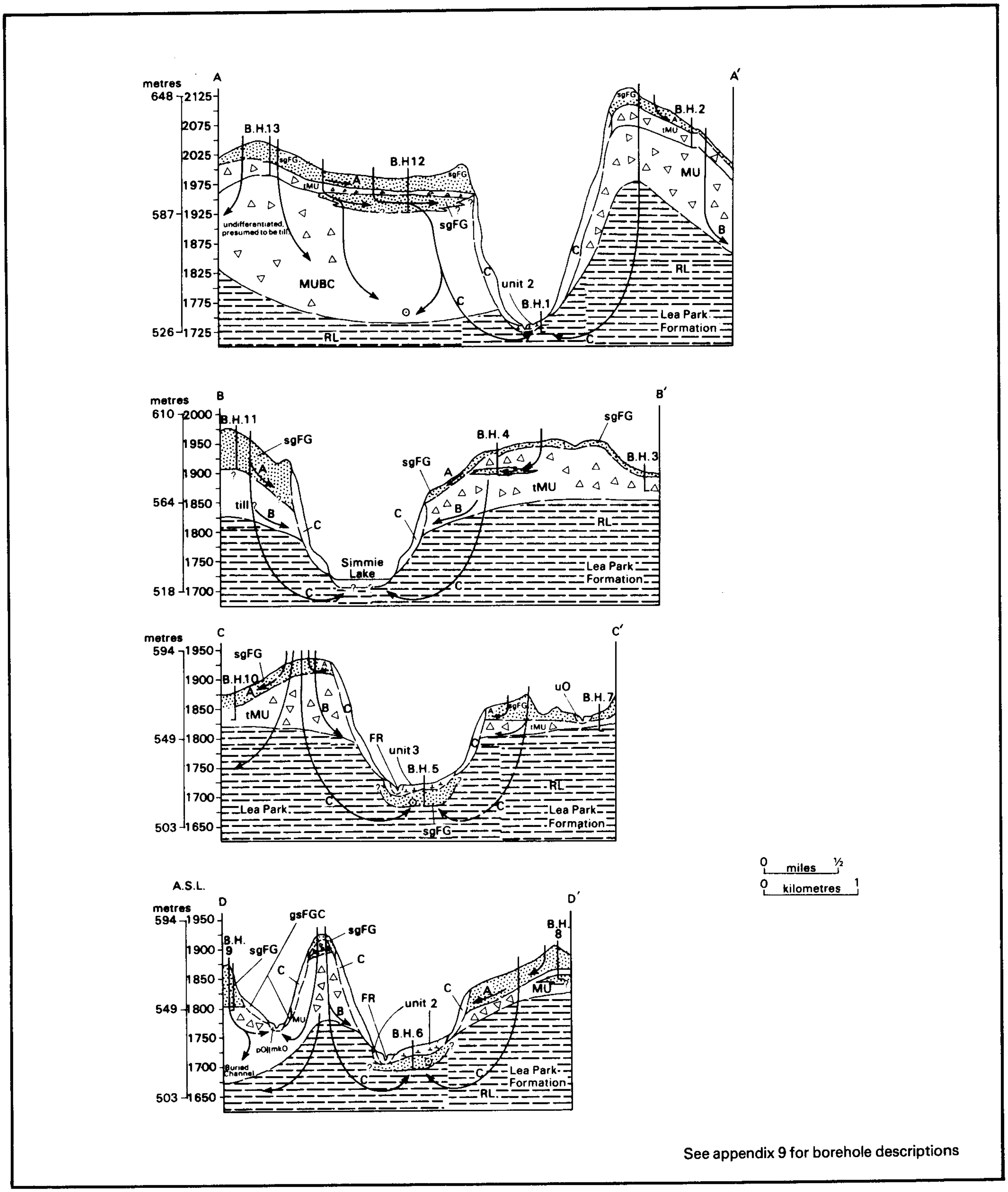


FIGURE 27. Cross-sections across Simmie Meltwater Channel

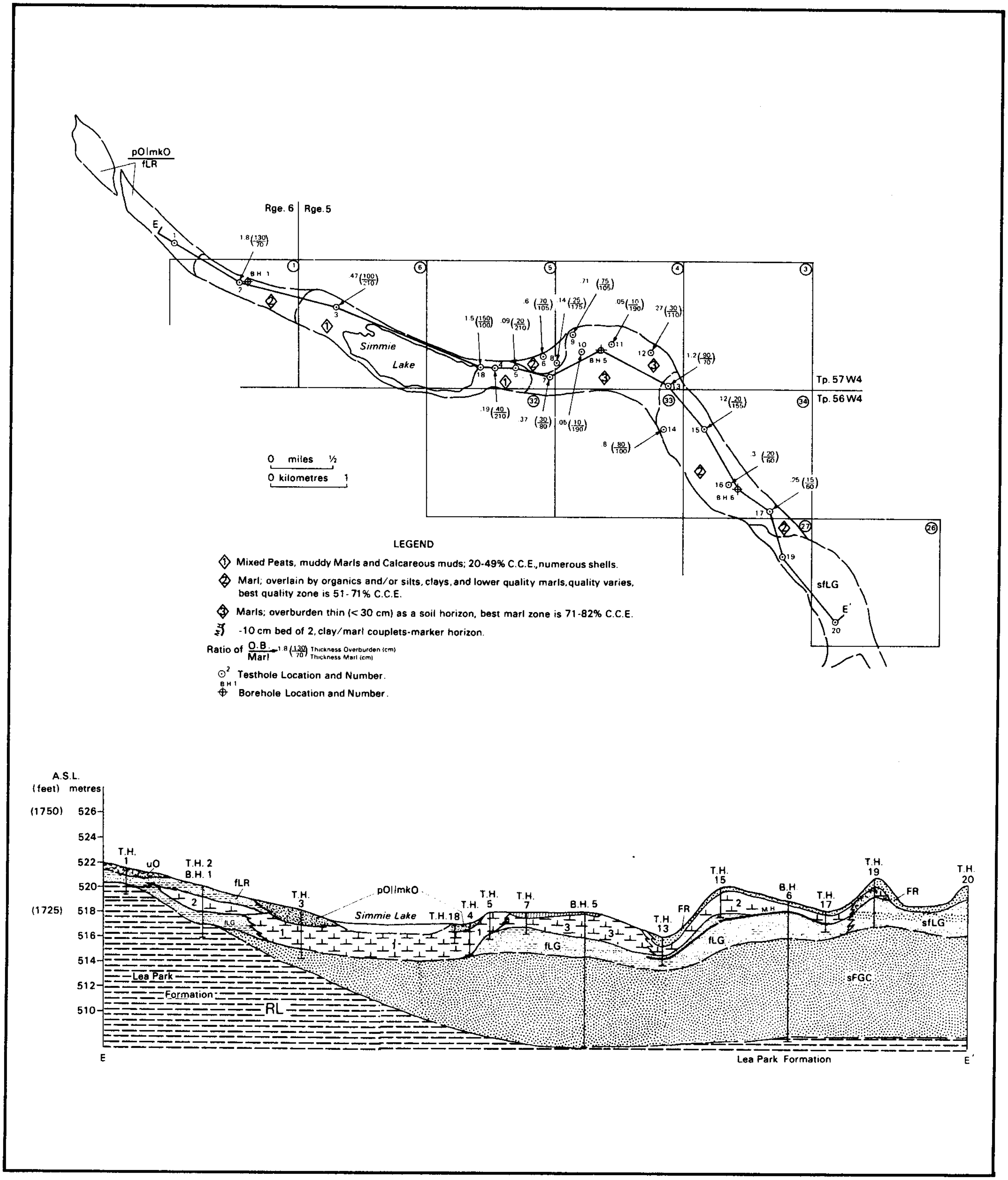


FIGURE 28. Geology, overburden/marl ratios, cross-section - Lindbergh deposit

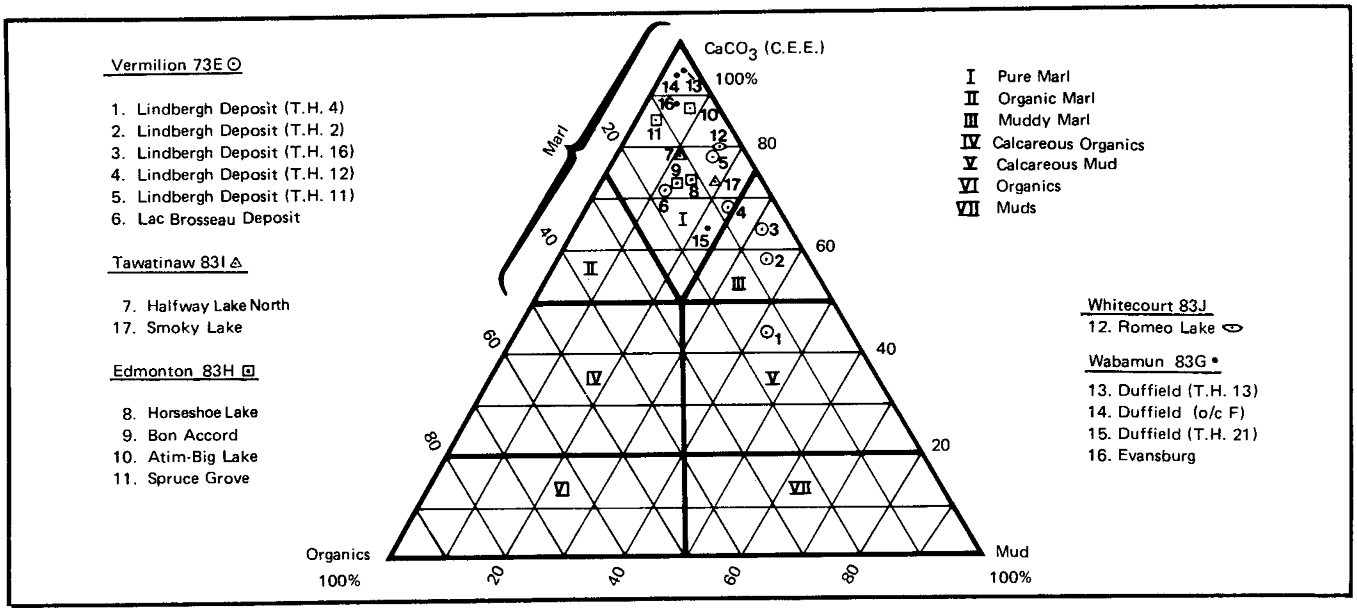


FIGURE 29. Classification of marl deposits from north-central Alberta

TABLE 7.
Marl reserves and properties - Lindbergh deposits

Area*	Sediment Thickness (metres)	Overburden Thickness (metres)	Overburden to Calcareous Sediment/ Marl Ratio	C.C.E.	Area (m^2)	Volume (m^3)	Location Wet or Dry
Unit 2 (Around Testhole 2)	.7	1.3 (one testhole)	1.8	51-70%	200 186	140 130	Wet
Unit 1 (Around Simmie Lake)	1.5 average	1.0 average	.67 average	20-50%	601 920	902 880	Wet
Unit 2 (Testhole 6 and 8)	1.0	.4 average	.4	51-70%	70 152	70 152	Wet
Unit 3 (Testhole 7,9,10,11,12)	1.0	.4 or less	.05 to .7	71-82%	642 369	642 369	Wet
Unit 2 (South End of Channel)	.6	.2 to .8	.12 to 1.2	51-70%	720 934	432 560	Dry

*See Figure 28

TABLE 8.
Marl Reserve Totals - Lindbergh Deposits

Totals	Volume (m^3)
Unit 1	902 880
Unit 2	642 842
Unit 3	642 369

Preliminary estimates of the volume of marl present, by map unit, are shown in Tables 7 and 8. In general terms, this is an excellent marl deposit, with greatest marl accumulations in areas around units 2 and 3 south and east of Simmie Lake. Access to the marl is good and the material is friable and non-tufaceous. The north and central portions of the deposit are water saturated.

WEST CENTRAL ALBERTA

EDSON (N.T.S. SHEET 83F)

The Edson map sheet was not explored extensively for marl because of the great distance from agricultural areas and limited road access; however, one deposit and eight reports are known from this area (Table 9). The area has considerable potential for future marl discoveries because it is underlain by the calcite-cemented Paskapoo Formation and calcareous glacial deposits in the western half. Also, strong relief produces strong groundwater flow systems of calcium-bicarbonate-rich water. Most deposits present are of the hillside spring (A-1), spring-fed lake (A-2), or seepage-ponded (B-2) classes.

Deposit 3 - Marlboro (N.T.S. 83F/10)

This deposit, adjacent to Highway 16 at 6, 7-53-20-W5 (Fig. 30), was discovered in 1911. A cement company was established in 1913 and a plant was established just east of the present townsite of Marlboro (Ross, 1976). Cement production continued for several years until the plant was purchased by Canada Cement and subsequently shut down.

The geological setting of the deposit is fluvial and lacustrine; marl deposition has been going on since the last deglaciation. Source waters for marl deposition appear to be groundwater moving from the highlands into the area and possibly from a buried preglacial valley that runs under the deposit (Vogwill, in prep.) (Fig. 30). *Chara* sp. were probably instrumental in the actual precipitation of marl.

The marl ranges from 1 to 2.75 m thick with all C.C.E. values greater than 74 percent and most greater than 85 percent. All testholes in this area appear in Figure 30. Generally, the marl lies below the water table. The calcium carbonate is entirely as marl, made up of calcite crystals approximately 1 μm in size. A bulk-size analysis appears in Table 3. Fossil pelecypods, gastropods, ostracods, and Chara fragments are abundant. Chemical analysis, X-ray diffraction and X-ray fluorescence show the marl to be Pure Marl (Fig. 35, Tables 10 and 11).

A detailed estimate of the volume of the deposit does not exist and was not done as part of this study. A rough estimate of the marl originally in place is 147 000 m^3 of 85 percent C.C.E. material (1 m minimum thickness) and the estimate of the material mined is 23 000 m^3, which leaves a remaining reserve of 124 000 m^3. The reserves of marl are of adequate quality and quantity for agricultural liming, but the distance to agricultural areas may prevent its use.

MOUNT ROBSON (N.T.S. SHEET 83E), WAPITI (N.T.S. SHEET 83L), AND BRAZEAU (N.T.S. SHEET 83C)

Several deposits (Table 9) of tufa associated with springs were reported for these areas by Borneuf (in prep.). None of these was visited as part of this study because of poor access and remoteness. Some, however, lie fairly close to the Grande Prairie farming area.

IOSEGUN LAKE (N.T.S. SHEET 83K)

This area was not explored for marl because it is distant from potential agricultural users and road access is poor. Four reports of marl and tufa deposits were made by Tokarsky (pers. comm.) while mapping the groundwater resources of the area for the Alberta Research Council (Table 9). None of these sites was visited for this study.

SOUTH CENTRAL ALBERTA

ROCKY MOUNTAIN HOUSE (N.T.S. SHEET 83B)

Ten deposits, one showing, and twenty-four reports of marl and tufa are known from the Rocky Mountain House area (Table 9). The presence of thin drift, calcareous Paskapoo Formation bedrock, strong local relief, and favorable groundwater chemistry and climate combine to make this a favorable area for

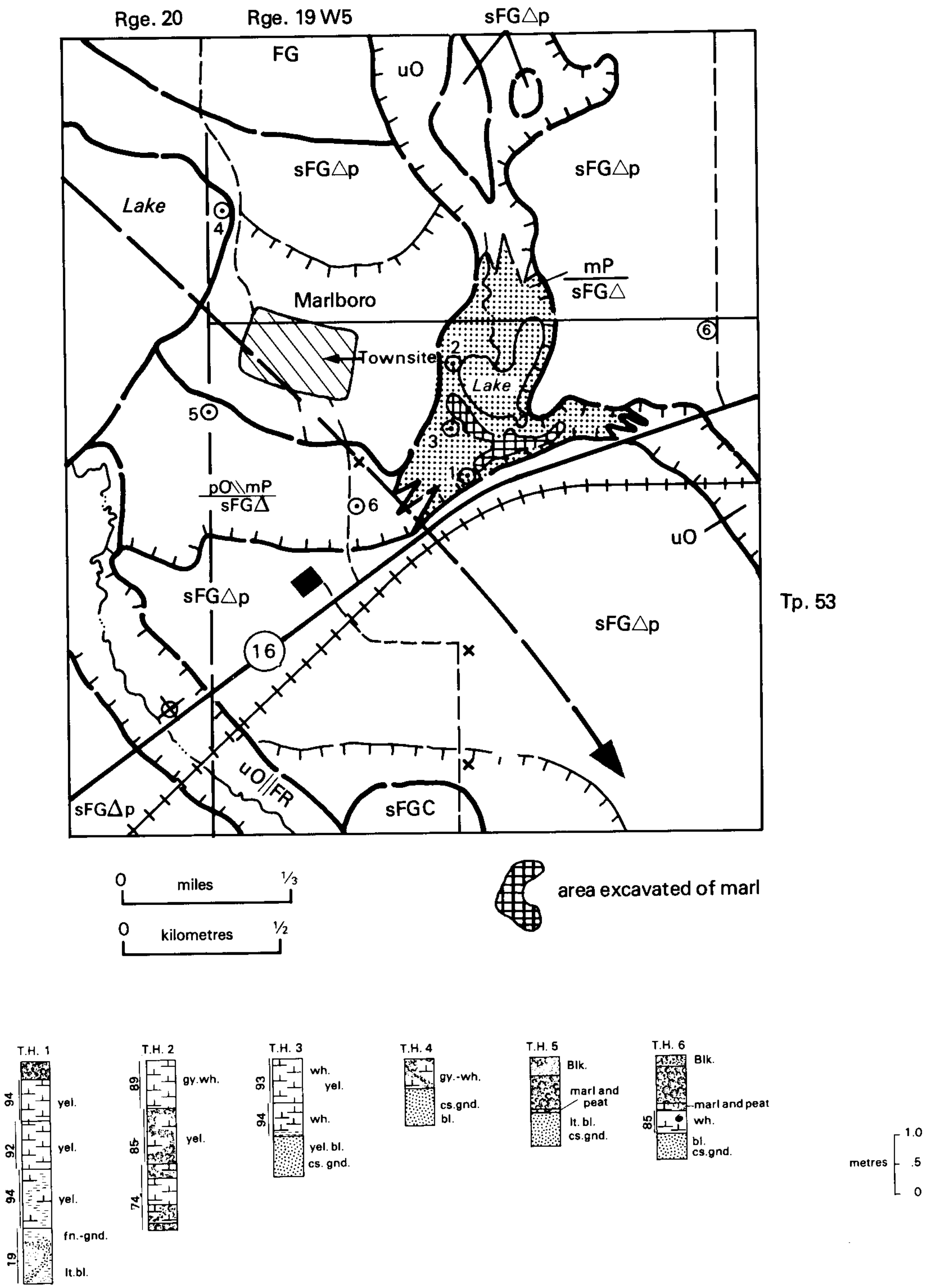


FIGURE 30. Surficial geology, testhole data, and access - Marlboro deposit

marl deposition (Appendix 1). Most deposits are associated with spring discharge and most are currently precipitating calcite. The eastern half of the area is most accessible by road and is also closest to potential agricultural uses, hence this is where exploration was concentrated.

Deposit 7 - Benalto (N.T.S. 83B/8)

This A-2 class deposit, first reported by Tokarsky (1971), is located north of the town of Benalto (NW6-39-2-W5). The deposit is in a small, dry lake basin (Fig. 31, Plate 1) resting on ground moraine. Marl deposition was probably by artesian groundwater discharging from the Paskapoo Formation (Fig. 31, Section A-B) into what was once a small lake. Today tufa is being deposited by a small spring discharging at the site.

Seven testholes were drilled to a maximum depth of 3.5 m, which showed C.C.E. values to decrease with depth from values of 80 percent in the upper 2 m at the center of the deposit (Fig. 31). Chemical analysis (Table 11) shows that very little clay is present and quartz detritus is less than 4 percent (Table 10 for additional details). The major contaminant is organic material (Fig. 35). Micrographs of tufa samples from near the spring showed calcite crystals in the 20 to 80 μm size range, which are euhedral when growing into a cavity and anhedral when not (Plates 7 and 8).

A central region near testholes 2, 3, and 7 appears to show 1.5 m of marl with grades of greater than 75 percent C.C.E. If the zone of effect for each hole is taken halfway to the next nearest hole, a volume of 62 000m^3 is obtained of 75 percent C.C.E. marl. If a C.C.E. value of 50 percent is acceptable, a 2 m thickness is available in the central region (Fig. 31) plus a 1 m thickness from the peripheral region; this yields a volume of 116 400 m^3 (Fig. 31).

The deposit is potentially usable for agricultural lime because of the large volume, high C.C.E., friable nature, reasonably easy access, and proximity to demand areas. Some of the deposit lies below the water table and some of the material would require crushing.

Deposit 10 - Raven (N.T.S. 83B/1)

This deposit, along the shoreline of a lake which is very shallow, is in the first stages of infilling by plant succession (Plate 5). The location is approximately 3 km south of Raven, Alberta (3-36-4-W5). The marl lake appears to be in contact with the local water table, which contains water with a Ca^{+2}, Mg^{+2}, HCO_3^- chemistry (Tokarsky, 1971) and the deposit appears to be a typical, actively precipitating shoreline fringe deposit (class C).

Ten testholes show the thickness of marl to vary from 10 cm at the southeastern shore of the lake to 220 cm at the northeastern shore, with C.C.E. values ranging from 22.5 to 67.25 percent (Fig. 33). It is not known if marl exists under the lake away from the shoreline. The zone of richest marl (>60 percent C.C.E.) forms a lens-shaped mass centred at testhole 6 (Fig. 32). Tufa was not observed.

If the marl occupies the area shown on Figure 33 (northeast deposit) with an assumed thickness of 0.9 m, the calculated volume is 128 900 m^3 of water-saturated marl and calcareous organic sediments (with a C.C.E. value of 40 to 70 percent).

As a source of agricultural lime, this deposit has the following drawbacks: access is poor and would require a 350 m road over a peat bog, conditions are very wet, and C.C.E. values are low (40 to 65 percent).

RED DEER (N.T.S. SHEET 83A)

Two deposits, three showings, and two reports of marl are known from the western half of this map sheet, the area underlain by the calcareous Paskapoo Formation (Table 9). Additional deposits in this western area may be discovered. The eastern half of the map area is underlain by the highly sodic Horseshoe Canyon Formation, which gives rise to Na^+ and SO_4^{-2} rich groundwater. The eastern area is also low in relief and too arid for optimal marl precipitation (see Appendixes 1 and 3).

Deposit 1 - Tees (N.T.S. 83A/16)

The Tees deposit, near the junction of Highways 12 and 50 near Tees, Alberta (13-19-40-23-W4), is along a creek that drains into Parlby Creek. Three springs issuing from the Paskapoo Formation were observed to be the source of calcium bicarbonate waters causing marl precipitation.

Seven testholes in the deposit showed mixed marl and tufa with the thickest amounts (1.5 m) near the

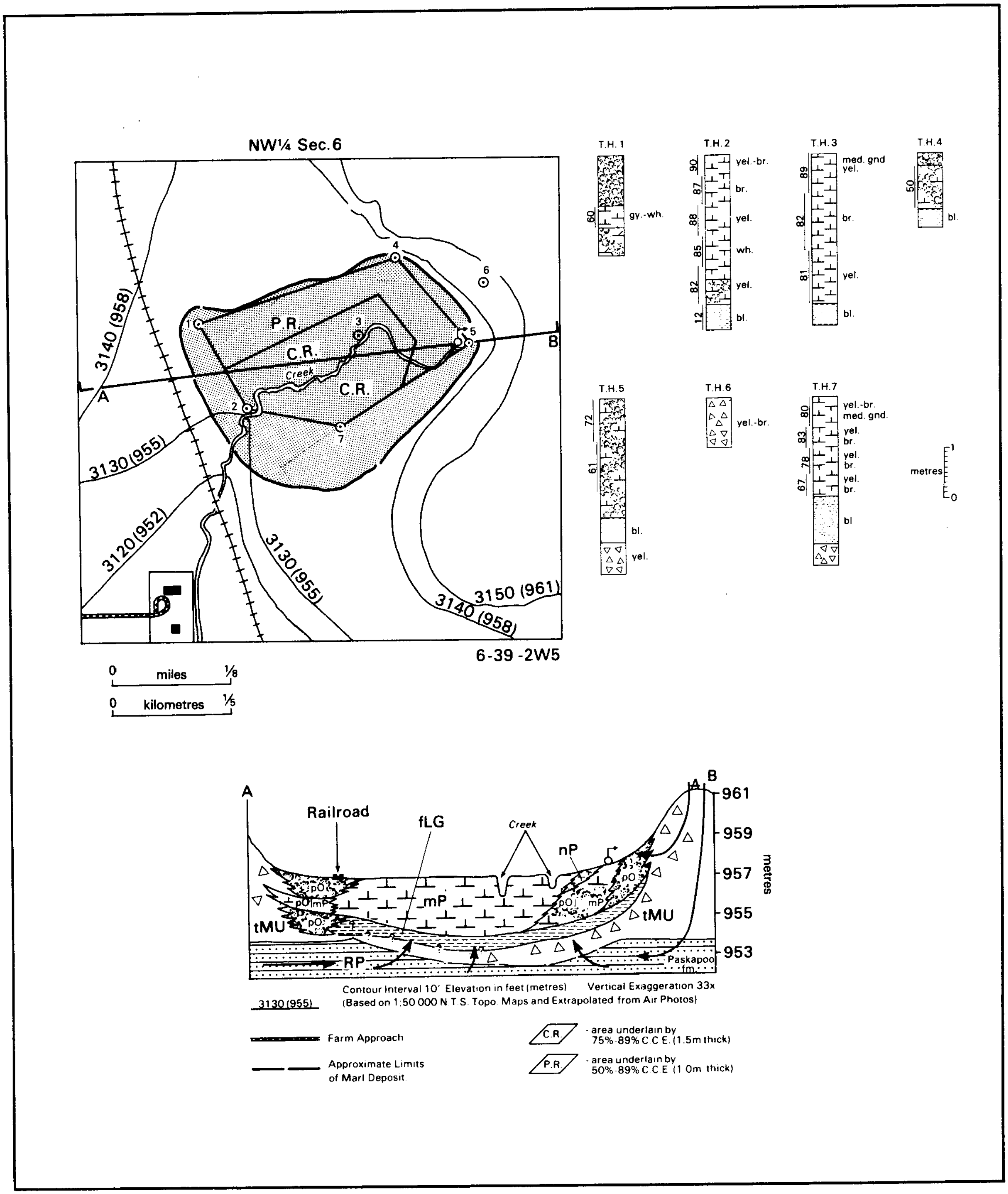


FIGURE 31. Topography, testholes, access, extent of deposit, and cross-section A-B - Benalto deposit

springs (or slightly down slope). C.C.E. values ranged from 50 to 90 percent. The carbonate thins and pinches out downstream near Highway 12. Clay mineral content is less than 3 percent. Quartz detritus is less than 8 percent and organic content is 8 percent (Tables 10 and 11, Fig. 35). Assuming an average thickness of 0.5 m, and a minimum grade of 50 percent C.C.E., 2500 m^3 are present. Overburden is absent.

The Tees deposit is one of the most easterly located in Alberta, contains no appreciable overburden, is accessible, and contains poor to good quality marl and tufa. Main drawbacks of the deposit are the wet location and the small quantities of coarse-grained tufa present.

Report 7 - Ponoka Limestone (N.T.S. 83A/12)

A Paskapoo Formation freshwater limestone bed was reported by M. Baaske of the Alberta Research Council (pers. comm.) The limestone is said to be within 0.5 m of the surface, and to be about 0.3 m thick. Baaske observed an outcrop of the limestone in 16-33-42-25-W4; however, the size of the bed is unknown. The limestone is well indurated and a single sample that was analyzed showed 53 percent C.C.E. (Table 11).

This limestone may find uses as an agricultural liming material, if crushed, as it is very close to the surface and has a moderately high C.C.E. content. Further work would need to be done to delineate the true extent, thickness, and quality of this deposit.

CALGARY (N.T.S. SHEET 82O)

Marl exploration was confined to the eastern third of the map area, these being the agricultural areas and also having good access. One deposit, one showing, and five reports of marl were found within the map area.

Deposit 1 - Didsbury (N.T.S. 82O)

This abandoned channel-glacial (D-1) deposit, west of Didsbury (SE13-31-4-W5), is in a flatbottomed glacial meltwater channel that is flanked by glaciofluvial sands and gravels and is currently occupied by a misfit stream (Fig. 34). This channel has cut into the bedrock Paskapoo Formation and groundwater is discharging as springs and seeps from bedrock aquifers.

The deposit is thought to have formed similar to other D-1 class deposits, shortly after deglaciation of the area. Marl is not currently precipitating.

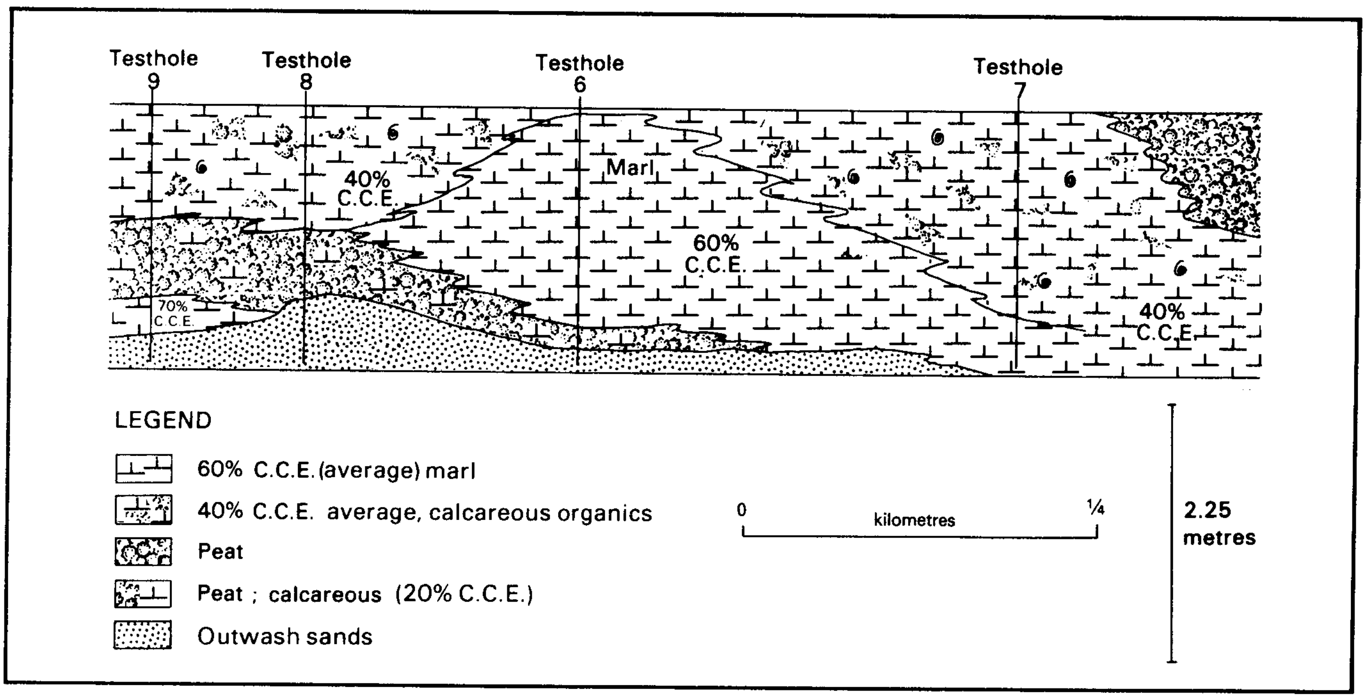


FIGURE 32. Carbonate mound sketch - Raven deposit

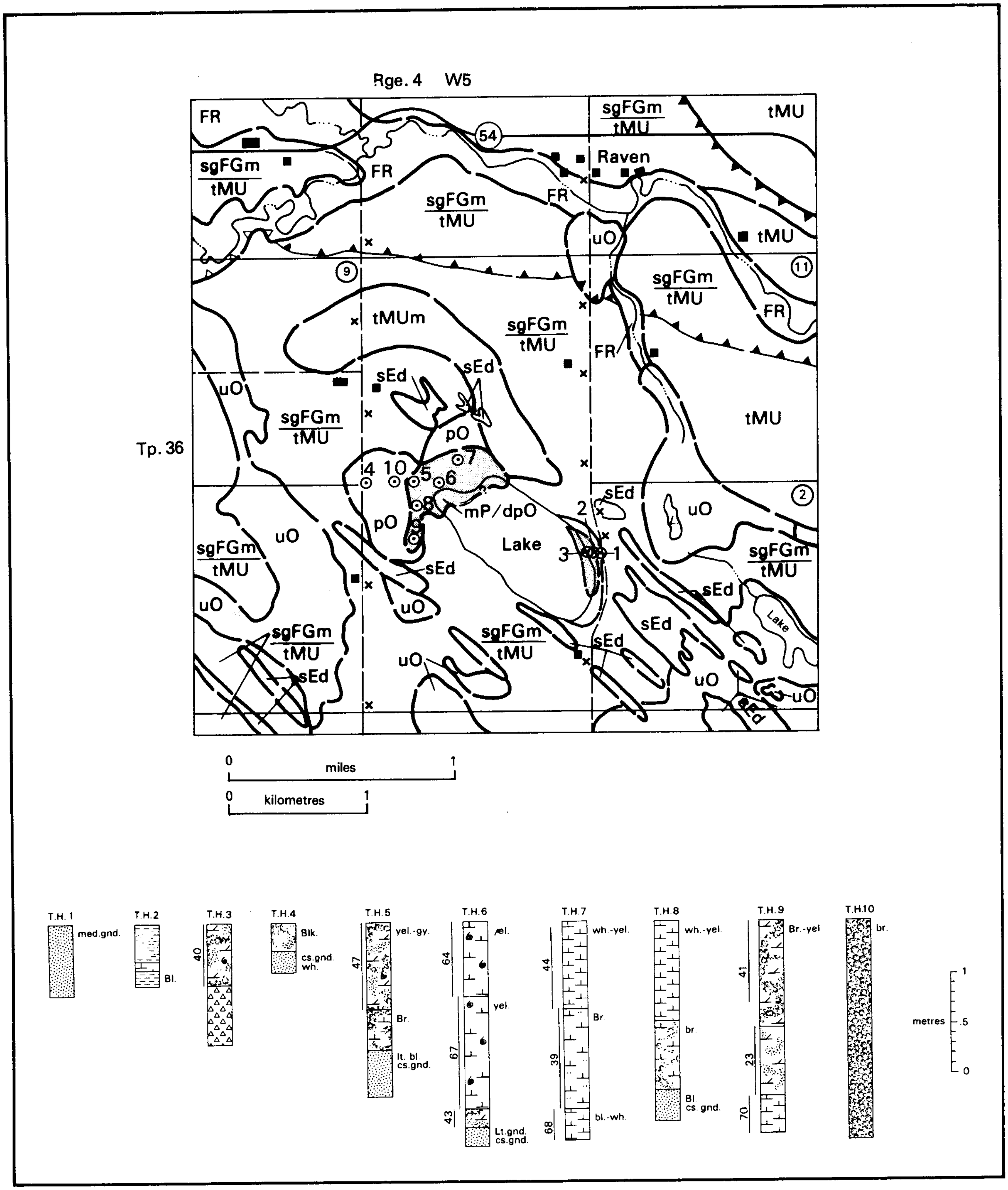


FIGURE 33. Surficial geology, access, and testhole data - Raven deposit

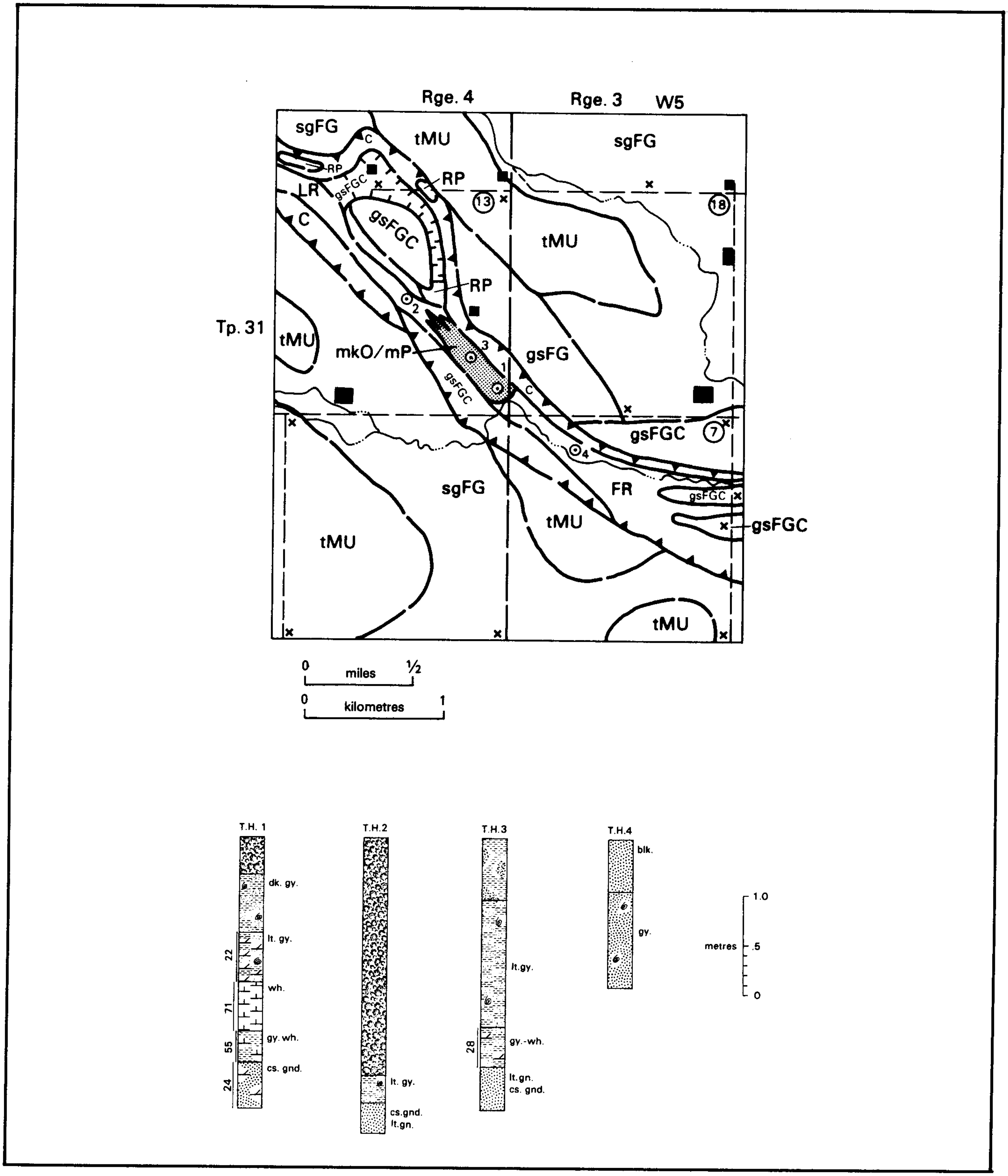


FIGURE 34. Surficial geology, testhole data, and location - Didsbury deposit

Marl was found in one of the four testholes drilled (Testhole 1, Fig. 34), and seems to be confined to the area near this testhole. The C.C.E. values encountered range from 21 to 70 percent, and the marl had a maximum thickness of 0.9 m.

A volume estimate of marl, 0.8 m over a radius of 90 m around testhole 1, gives a volume of 20 400 m^3 with a minimum C.C.E. content of 55 percent. This marl has an overburden of peat or calcareous sediments at least 1.5 m thick.

This marl deposit, one of the most southerly in the province, is readily accessible. Negative aspects of the deposit are a low C.C.E. value, small quantities, wet location and high ratio of overburden to marl thicknesses.

DRUMHELLER (N.T.S. SHEET 82P)

The only deposit in this map area is in the Hand Hills. Two showings also exist (Table 9). Potential for future discoveries in this area is very limited due to dry climatic conditions, slow groundwater movement, and low relief (Appendix 3).

Deposit 1 - Hand Hills (N.T.S. SHEET 82P/9)

Holter (1974a) examined this deposit and his results are summarized here. Varying quantities of marl and calcareous sediments occur in the Pliocene Hand Hills Formation, below the gravels that cap the hills.

The Hand Hills rise to an elevation of 1067 m, approximately 152 m above the surrounding plains. The Hand Hills Formation that caps the hill consists of an upper 3 m of conglomerate underlain by 8 m of calcareous, silty shales, sandstones, and shales. Holter interpreted the marl to have been deposited by groundwater discharging on the flanks of the hills as seeps.

A series of testholes defined calcareous sediments with C.C.E. values of 30 to 40 percent with marl being encountered in only one hole (30-17-10-5-W4). Low quality and quantity of material makes this deposit unsuitable as a source of agricultural lime. Other hillside-seepage deposits might be found in the Wintering Hills southwest of the Hand Hills, which are also capped by the Hand Hills Formation.

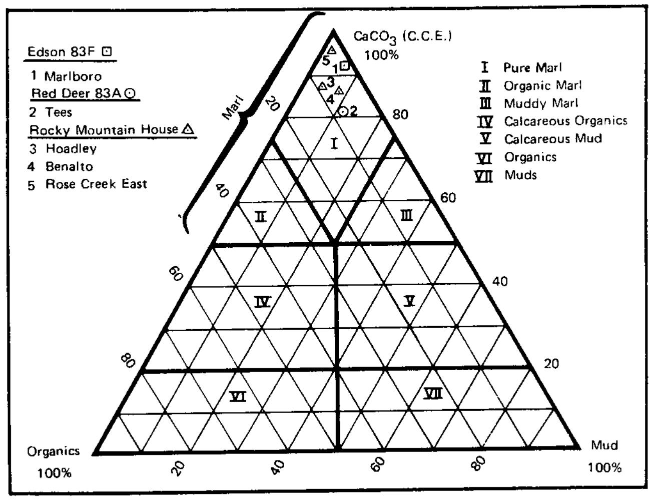


FIGURE 35. Classification of deposits from west-central and south-central Alberta

WAINWRIGHT (N.T.S. SHEET 73D)

No deposits, showings, or reports of marl were found in this area, presumably because of an unfavorable dry climate and groundwater chemistry (see Appendix 3 for a detailed discussion of factors resulting in a lack of marl formation in eastern Alberta).

SOUTHERN ALBERTA

A brief reconnaissance of portions of southern Alberta was made in an attempt to determine the potential for marl deposits in the area (Fig. 2). Testholes were made in some of the major lakes in settings favorable for marl, based on findings elsewhere in the province. No showings of marl or tufa were found and the entire region has a very low potential for marl deposits for the following reasons:

1. Annual precipitation is low, 33 to 51 cm with a high potential evapotranspiration, which makes groundwater recharge a very slow process.
2. Sodium sulfate and sodium bicarbonate are characteristically the dominant ions in the groundwater of the region.
3. Springs or areas of seepage are not abundant. Most groundwater discharges into lake basins, which seasonally dry up forming alkali flats.

Potential exploration areas for marl may exist in the Foothills-Rocky Mountains regions of southern Alberta. Some tufa reports are known in the Kananaskis region (Table 9).

TABLES 9, 10, AND 11

EXPLANATORY NOTES TO ACCOMPANY TABLE 9

Site Number

Corresponds to number plotted on Figure 38.

Legal Location

Determined as accurately as possible from map reference, using the Dominion Land Survey System. Location is given by: Legal Subdivision - Section - Township - Range - West of a Meridian.

Name

Most deposits are named after some nearby geographic feature.

NATURE OF DEPOSIT

Type of Occurrence

Classified according to degree of documentation as:
Deposit: several testholes outlining most or all of the occurrence.
Showing: one or two testholes only; limits of the occurrence unknown.
Report: occurrence indicated from reputable sources; no testhole information available; limits unknown.

Lithology

Calcareous Sediments: calcium carbonate equivalence (C.C.E.) content is between 20 and 49 percent.
Limestone: well indurated rock containing a C.C.E. value of greater than 50 percent.
Marl: if the C.C.E. content is greater than 50 percent, and the calcium carbonate is friable and fine-grained.
Mixed: if the occurrence involves a mixture of both marl and tufa.
Tufa: if the C.C.E. content is greater than 50 percent, and the calcium carbonate is spongy, porous, and coarse-grained.

Quality

Measure of calcium carbonate percentage in the material as determined from laboratory analysis, expressed as calcium carbonate equivalence (C.C.E.).

TABLE 9.

Summary Description of Marl and Tufa Occurrences in Alberta

Site Number	Legal Location	Name	Type of Occurrence	Nature of Deposit: Lithology	Nature of Deposit: Quality	Thickness (m)
NORTHWESTERN ALBERTA						
Grande Prairie 83M						
1	5+6-16-78-6-W6	Spirit River	Deposit	Marl	Submarginal-Good	0.5
2	12-21-78-7-W6	Spirit River West	Deposit	Mixed	Poor	0.4
3	6+3-15-78-12-W6	Bay Tree A	Deposit	Marl	Submarginal-Good	2.5
4	6+7-11-78-12-W6	Bay Tree B	Report	Mixed?	-	-
5	2+3-31-75-13-W6	Swan Lake	Report	Marl	-	0.3
6	10-16-74-13-W6	Demmit	Deposit	Marl	Good	0.7
7	SW 29-71-9-W6	Huallen	Report	Marl	Poor	-
8	SE 17-71-6-W6	Flyingshot Lake	Showing	Calcareous Sediments	Submarginal	0.5
9	10-6-80-3-W6	83M-9	Report	Tufa or Mixed	-	-
10	1-9-76-1-W6	83M-10	Report	Tufa or Mixed	-	-
Winagami 83N						
1	SW+NE 20-72-26-W5	Debolt Creek	Deposit	Marl	Poor	0.2
2	SE 33-70-26-W5	Cornwall Creek	Deposit	Marl	Poor	0.2
3	SE+SW 5-71-24-W5	Sturgeon Lake	Deposit	Marl	Poor-Good	0.5-0.9
4	SW 36-73-23-W5	Wabatanisk Creek	Deposit	Marl	Poor	0.2
5	4-71-19-W5	Snipe Lake	Deposit	Marl	Poor-Fair	0-1.5
Peace River 84C						
1	12-14-82-24-W5	Grimshaw	Deposit	Marl, minor Tufa	Good	0-4.0
2	14-24-82-24-W5	Grimshaw North	Deposit	Marl, minor Tufa	Good	0-0.5
3	1+8-23-82-24-W5	Showing A	Showing	Mixed	-	0.3

Submarginal: 20 to 49 percent C.C.E. (as in Calcareous Sediments).
Poor: 50 to 65 percent C.C.E.
Fair: 66 to 79 percent C.C.E.
Good: 80 to 100 percent C.C.E.

Thickness

Average thickness or range of thicknesses in the deposit, expressed in metres.

Size

Quantity of material present, determined from measured thickness and extent:

Insignificant: material is present as scattered lenses or pods in quantities too small to recover.
Small: less than 10 000 cubic metres
Moderate: 10 000 to 50 000 cubic metres
Moderately Large: 50 000 to 150 000 cubic metres
Large: greater than 150 000 cubic metres

SITE CONDITIONS

Overburden Thickness

Depth of burial of deposit expressed in metres.

Road Access

Distance from deposit to nearest road.

Moisture

Natural moisture conditions of deposit, due to local surface water or groundwater conditions.

Geographic Setting

Local geographic conditions.

Class of Deposit

Classified according to origin, geological and geographical setting of deposit (see Text).

			Site Conditions		
Size (m^3)	Overburden Thickness (m)	Road Access (km)	Moisture	Geographic Setting	Class
Moderate	<0.2	0.2	Well drained	Hillside	B-1
Small	0-0.1	0.2	Ponded, very wet	Gentle slope	B-2
Moderate	0-1.0	0.8	Ponded, very wet	Small pond	B-2
-	0-?	0.4	Wet, seepages	Hillside	B-2??
-	0-?	-	Wet	Lake	-
Small	0.15	2.4	Drained	Hillside	B-1
-	-	-	-	-	-
-	0.2	Roadside	Well drained	Drained bog	-
-	0-?	Poor?	Wet, active spring	-	-
-	0-?	-	Wet, active spring	-	-
Small	0.2	<0.2	Well drained	Lakeshore	C-2
Moderate	0.2	Roadside	Well drained	Flat terrace	E-1
Moderately Large	<0.3	0.2	Partially drained	Lakeshore	C-2
Insignificant	1.0	1.6	Well drained	Creek floodplain	D-2
Moderately Large	0.3	0.6	Well drained to saturated	Lakeshore	C-2
Moderately Large	0-0.1	Roadside	Well drained	Flat fields - mound	A-3
Moderate	0.2	Roadside	Well drained	Flat fields	-
-	0.1	Roadside	Well drained	Flat fields	-

TABLE 9 (continued)

Site Number	Legal Location	Name	Type of Occurrence	Nature of Deposit: Lithology	Nature of Deposit: Quality	Thickness (m)
NORTHWESTERN ALBERTA (continued)						
4	9-7-82-25-W5	Showing B	Showing	Marl	-	0.05
5	4+5+9+10-87-22-W5	Whitemud River	Report	Marl	Fair?	-
Clear Hills 84D						
1	3+6-35-83-13-W6	Campbell	Deposit	Tufa, minor Marl	Poor-Good	0-2.25
2	16-6-84-12-W6	Epp	Deposit	Marl	Good	0-1.0
NORTH–CENTRAL ALBERTA						
Whitecourt 83J						
1	4-14-59-10-W5	McGregor	Deposit	Marl	Fair-Good	0-3.6
2	6-9-59-10-W5	Underwood	Deposit	Marl	Good	1.0
3	29+30+31-58-6-W5	Romeo Lake	Deposit	Marl	Poor-Fair	1.0
4	1-2-61-4-W5	Shoal Lake	Showing	Calcareous Sediments	Submarginal	-
Tawatinaw 83I						
1	12-30-64-20-W4	Kinikinik Lake	Deposit	Marl	Fair	0.05
2	6-6?-18-W4	Valley Lake	Report	Marl	-	-
3	35+36-59-17-W4	Smoky Lake	Deposit	Marl	Poor-Fair	0.2-1.0
4	3+4-60-24-W4	Halfway Lake	Deposit	Marl	Poor-Fair	up to 6.0
Wabamun 83G						
1	16-22-56-14-W5	Shiningbank Lake	Deposit	Marl	Submarginal-Poor	0.9
2	13+14-24-54-8-W5	Evansburg	Deposit	Mixed	Fair-Good	1.0
3	10-56-6-W5	Brock Lake	Deposit	Marl	Poor-Fair	0.15
4	1+8-25-54-5-W5	Lac Ste. Anne	Deposit	Marl	Poor-Fair	1.2+
5	11+14-25-53-1-W5	83G-5	Report	Marl?	-	-
6	14+15-36-53-2-W5	Kilini Creek	Report	Marl?	-	-
7	12-30-52-2-W5	Johnnys Lake	Showing	Calcareous Sediments	Submarginal	0.9
8	12-8-52-2-W5	Jackfish Lake	Showing	Calcareous Sediments	Submarginal	1.7
9	29+30-51-2-W5 25+36-51-3-W5	Duffield	Deposit	Marl	Poor-Good	0.5-3.0
10	6-3-50-4-W5	Creekland	Deposit	Marl	Poor-Good	0-0.80
11	10+11-33-46-6-W5	Buck Lake	Showing	Marl	Poor	0.20
12	9-9-50-12-W5	83G-12	Report	Tufa	-	-
13	13-34-53-1-W5	83G-13	Showing	Calcareous Sediments	Submarginal	2.3
14	16-3-53-1-W5	83G-14	Showing	Calcareous Sediments	Submarginal	0.50
15	10-14-47-10-W5	83G-15	Report	Tufa	-	-
16	15-14-47-10-W5	83G-16	Report	Tufa	-	-
17	15-14-47-10-W5	83G-17	Report	Tufa	-	-
Edmonton 83H						
1	16-18-53-25-W4	Horseshoe Lake	Deposit	Marl	Fair	1.5
2	1+8-6-53-25-W4	Deposit A	Deposit	Marl	Fair-Good	0.6
3	16-30-52-25-W4	Deposit B	Deposit	Marl	Fair-Good	1.5
4	5-29-52-25-W4	Deposit C	Deposit	Marl	Fair	1.0

Size (m^3)	Overburden Thickness (m)	Road Access (km)	Site Conditions Moisture	Geographic Setting	Class
-	0-0.1	Roadside	Well drained	Flat fields	-
-	-	9.7	-	Large bog area	-
Small	0.0	0.8	Active spring	Flat fields - mound	A-3
Small	0.2	0.8	Seepages	Hillside	B-1
Moderate	0.3	Roadside	Wet	Hillside	B-1
Small	0.2	0.2	Partially drained	Hillside	B-1
-	0.5	0.2-2.4	Well drained	Lakeshore	C-2
-	-	Roadside	Wet	Lakeshore	-
-	1.55	Roadside	Wet	Bog area	C-2?
-	-	-	-	Lake bed?	-
-	0.5-1.5	<0.2	Wet	Marshland	D-1
Large (>4 million)	Variable	Variable	Wet	Lake and bogs	B-2
-	0.6	0.4	Partially drained	Lowlands	C-2
Moderate	0	0.2	Wet, active seepage	Hillside	A-1 or B-1
Small	0.9	Roadside	Wet	Under a lake	C-2
-	1.0	Roadside	Wet	Below lake	C-2
-	-	0.4-0.8	Wet	Large bog	-
-	-	-	Wet	Large bog	-
-	3.1	-	Wet	Lakeshore	C-2?
-	0.3	0.2	Wet	Below Lake	-
Large (>1 million)	0-2.0	0-0.2	Wet to well drained	Abandoned oxbow lake	D-2
Moderate	0.5	0.4	Well drained	Hillside	B-1
-	0.15	Roadside	Well drained	Lakeshore	C-2
-	-	-	Active spring	-	-
-	0.7	Roadside	Wet	Lake bed	-
-	2.5	Roadside	Wet	Bog area	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
Moderately Large	0	Roadside	Wet	Lake bed	B-2
Moderate	0	Roadside	Wet	Bog	B-2
Large	0	Roadside	Wet	Bog	B-2
Moderate	0	Roadside	Wet	Bog	B-2

TABLE 9 (continued)

Site Number	Legal Location	Name	Type of Occurrence	Nature of Deposit: Lithology	Nature of Deposit: Quality	Thickness (m)
NORTH–CENTRAL ALBERTA (continued)						
Edmonton 83H (continued)						
5	19+20+21+22+27+28+ 29-53-26-W4	Big Lake, Atim Lake	Deposit	Marl	Poor-Good	1.0 or greater
6	15-7-53-26-W4	Acheson	Deposit	Marl	Fair-Good	1.0
7	SW+NW 1-53-27-W4	83H-7	Report	Marl	-	-
8	SW 8-53-26-W4	83H-8	Report	Marl	-	-
9	5-16-54-27-W4	Gladu Lake	Showing	Marl	Poor	2.2
10	8-32-53-27-W4	Gladu Hills	Showing	Calcareous Sediments	Submarginal	0-0.5
11	1-29-53-27-W4	Spruce Grove	Deposit	Marl	Fair-Good	1.0
12	14-31-50-27-W4	83H-12	Showing	Marl	Poor	0.90
13	1-21-51-26-W4	83H-13	Showing	Calcareous Sediments	Submarginal	0.50
14	2-4-57-24-W4	Legal	Showing	Calcareous Sediments	Submarginal	0.30
15	12-57-24-W4 NE 31-56-23-W4	Bon Accord	Deposit	Marl	Submarginal-Good	1.0
Vermilion 73E						
1	14+23-56-12-W4	Lac Brosseau	Deposit	Marl	Submarginal-Fair	1.1
2	3+4+5+6-57-5-W4 33+34-56-5-W4	Lindbergh	Deposit	Marl	Submarginal-Good	0.6-1.90
3	4-14-55-5-W4	Heinsburg	Showing	Calcareous Sediments	Submarginal	0.50
4	6-24-57-13-W4	Saddle Lake	Showing	Marl	Fair	
WEST–CENTRAL ALBERTA						
Edson 83F						
1	SE 1-55-21-W5	83F-1	Report	Marl	-	-
2	NW 23-56-15-W5	Kathleen Lake	Report	Marl, minor Tufa	-	-
3	6+7-53-20-W5	Marlboro	Deposit	Marl	Fair-Good	1.0-2.75
4	13-28-46-26-W5	83F-4	Report	Tufa	-	-
5	14-8-48-26-W5	83F-5	Report	Tufa	-	-
6	1-31-51-17-W5	83F-6	Report	Tufa	-	-
7	6-32-51-25-W5	83F-7	Report	Tufa	-	-
8	4-32-52-26-W5	83F-8	Report	Tufa	-	-
9	16-4-53-22-W5	83F-9	Report	Tufa	-	-
Mount Robson 83E						
1	2-13-55-1-W6	83E-1	Report	Tufa	-	-
2	15-36-57-3-W6	83E-2	Report	Tufa	-	-
Iosegun 83K						
1	9-66-21-W5	83K-1	Report	Tufa	-	-
2	22-61-15-W5	83K-2	Report	Mixed	-	-
3	28-61-16-W5	83K-3	Report	Mixed	-	-
4	SW 6-62-19-W5	83K-4	Report	Mixed	-	-

Size (m^3)	Overburden Thickness (m)	Road Access (km)	Site Conditions Moisture	Geographic Setting	Class
Large (>2 million)	Highly variable	0.8	Wet	Lake and lowland	B-2
Moderate	0	Roadside	Wet	Small pond	B-2
-	-	Roadside	Wet?	Bog	-
-	-	-	Wet?	Bog	-
-	0.2	0.2	Wet	Bog	D-1
Insignificant	2.4	Roadside	Well drained	Upland hills	H-1
Moderate	0-0.10	Roadside	Wet	Bog area	B-2
-	0	Roadside	Wet	Marshland	B-2
-	0	Roadside	Wet	Lake bed	B-2
-	0.50	Roadside	Wet	Marshland	-
Large (>½ million)	0-1.0	Roadside to 0.2	Wet	Marshland	D-1
Moderate +?	0-0.5	Roadside-0.2	Wet	Marshland	C-1
Large (>1 million)	0.10-1.50	Roadside-0.2	Wet to well drained	Lowland, marshland, lake bed	D-1
-	2.0	Roadside	Wet	Marshland	D-1
Moderately Large?	0-0.5 ?	0.5	Wet, active seepages	River terrace	B-2
-	0-?	4	Wet	Lake basin	A-2?
-	0-?	-	Wet	Lake basin	A-2
Moderately Large	0-0.10	<0.2	Wet	Small lake	A-2
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	0-?	-	-	-	-
-	0-?	-	Wet	-	-
-	0-?	-	Active spring, wet	-	-
-	0-?	-	Wet	-	-

TABLE 9 (continued)

Site Number	Legal Location	Name	Type of Occurrence	Nature of Deposit: Lithology	Nature of Deposit: Quality	Thickness (m)
WEST—CENTRAL ALBERTA (continued)						
Wapiti 83L						
1	5-9-58-4-W6	83L-1	Report	Tufa	-	-
2	1-35-59-2-W6	83L-2	Report	Tufa	-	-
3	10-3-59-4-W6	83L-3	Report	Tufa	-	-
4	2-14-62-4-W6	83L-4	Report	Tufa	-	-
5	1-2-64-1-W6	83L-5	Report	Tufa	-	-
6	1-28-64-1-W6	83L-6	Report	Tufa	-	-
7	3-2-64-2-W6	83L-7	Report	Tufa	-	-
8	12-35-64-2-W6	83L-8	Report	Tufa	-	-
Brazeau 83C						
1	7-27-37-18-W5	83C-1	Report	Tufa	-	-
2	2-22-43-20-W5	83C-2	Report	Tufa	-	-
3	14-27-43-20-W5	83C-3	Report	Tufa	-	-
4	14-33-44-19-W5	83C-4	Report	Tufa	-	-
5	3-23-44-20-W5	83C-5	Report	Tufa	-	-
6	6-22-44-22-W5	83C-6	Report	Tufa	-	-
7	16-22-44-22-W5	83C-7	Report	Tufa	-	-
8	12-31-45-16-W5	83C-8	Report	Tufa	-	-
9	12-18-45-24-W5	83C-9	Report	Tufa	-	-
SOUTH—CENTRAL ALBERTA						
Rocky Mountain House 83B						
1	15-31-44-3-W5 2-6-45-3-W5	Hoadley	Deposit	Marl, minor Tufa	Fair-Good	1.0-3.0
2	31-45-2-W5	Lloyd Creek	Deposit	Mixed	Poor-Good	1.0-2.0
3	SE 16-45-1-W5	Westerose	Deposit	Mixed	Fair-Good	0.5
4	19+29+30-42-6-W5	Rose Creek	Deposit	Mixed	Good	0.5-1.0
5	14-19-40-2-W5	Medicine Lodge Hills	Deposit	Marl, minor Tufa	Good	0.9
6	12-40-4-W5 7-40-4-W5	Gabriel Lake	Showing	Calcareous Sediments	Submarginal	1.25
7	NW 6-39-2-W5	Benalto	Deposit	Marl	Poor-Good	1.5
8	NE21+SE28-35-6-W5	Caroline	Deposit	Tufa	Poor-Good	1.0
9	1-26-35-6-W5	Caroline East	Deposit	Tufa	Fair-Good	0.5
10	3-36-4-W5	Raven	Deposit	Marl	Submarginal-Fair	0.9
11	13-36-35-7-W5	83B-11	Report	Tufa	-	-
12	16-31-39-9-W5	83B-12	Report	Tufa	-	-
13	25-37-12-W5	83B-13	Report	Tufa	-	-
14	12-7-39-7-W5	83B-14	Report	Tufa	-	-
15	8-10-40-11-W5	83B-15	Report	Tufa	-	-
16	3-5-36-5-W5	83B-16	Report	Tufa	-	-
17	16-17-35-14-W5	83B-17	Report	Tufa?	-	-
18	7-5-36-14-W5	83B-18	Report	Tufa	-	-
19	7-4-39-12-W5	83B-19	Report	Tufa	-	-

Size (m^3)	Overburden Thickness (m)	Road Access (km)	Site Conditions: Moisture	Site Conditions: Geographic Setting	Class
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
Small	0-1.0	Roadside	Wet, active spring	Hillside	B-1
Small	0	0.2	Wet, active spring	Hillside	A-1
Small	0-1.0	0.1	Wet, active spring	Hillside	A-1
Moderate	0-0.2	Roadside	Wet, active spring	Hillside	A-1 (3 deposits)
Small	0.1	Roadside	Partially drained	Hillside	B-1
-	0.6	0.2	Wet	Lake bed	-
Moderately Large	0-0.1	0.2	Wet to partially drained	Drained lake bed	A-2
Moderate	0-0.2	Roadside	Wet, active springs	Hillside	A-1
Small	0	Roadside	Wet, active springs	Hillside	A-1
Moderately Large	Variable	0.4	Wet, shoreline	Shoreline, lake	C-1
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	Wet, active spring	-	-
-	-	-	Wet, active spring	-	-
-	-	-	Wet, active spring	-	-
-	-	-	-	Small mound	-

TABLE 9 (continued)

Site Number	Legal Location	Name	Type of Occurrence	Nature of Deposit: Lithology	Nature of Deposit: Quality	Thickness (m)
SOUTH—CENTRAL ALBERTA (continued)						
Rocky Mountain House 83B (continued)						
20	8-9-46-4-W5	83B-20	Report	Mixed?	-	-
21	14-8-39-11-W5	83B-21	Report	Tufa	-	-
22	7-5-46-11-W5	83B-22	Report	Mixed	-	-
23	1-27-46-13-W5	83B-23	Report	Tufa	-	-
24	6-30-40-7-W5	83B-24	Report	Marl?	-	-
25	1-17-40-11-W5	83B-25	Report	Mixed?	-	-
26	9-40-13-W5	83B-26	Report	Marl?	-	-
27	1-15-40-13-W5	83B-27	Report	Mixed?	-	-
28	4-27-41-1-W5	83B-28	Report	Tufa	-	-
29	1-22-41-8-W5	83B-29	Report	Marl?	-	-
30	9-25-41-14-W5	83B-30	Report	Marl?	-	-
31	1-27-41-14-W5	83B-31	Report	Tufa	-	-
32	8-15-42-13-W5	83B-32	Report	Mixed?	-	-
33	2-32-43-4-W5	83B-33	Report	Mixed?	-	-
34	13-20-44-6-W5	83B-34	Report	Mixed?	-	-
35	1-4-46-1-W5	83B-35	Deposit	Tufa	Good	0.6
Red Deer 83A						
1	13-19-40-23-W4	Tees	Deposit	Mixed	Poor-Good	0.5-1.5
2	3-36-42-25-W4	Parlby Creek	Showing	Calcareous Sediments	Submarginal	0.1-0.3
3	16-26-42-28-W4	Gull Lake	Deposit	Mixed	Fair-Good	1.0
4	10-14-42-26-W4	Morningside	Showing	Marl	Fair	0.55
5	5-33-45-25-W4	Bearhills Lake	Showing	Marl	Poor	0.05
6	14-13-38-26-W4	Hillsdown	Report	Marl	-	-
7	16-33-42-25-W4	Ponoka	Report	Limestone	Poor	0.3?
Calgary 820						
1	SE 13-31-4-W5	Didsbury	Deposit	Marl	Poor-Fair	0.8
2	8-31-27-3-W5	Big Hill Creek	Showing	Marl	Fair	0.3
3	14-29-26-3-W5	Big Hill Springs	Report	Tufa	-	-
4	4-3-26-4-W5	820-4	Report	Tufa	-	-
5	13-31-24-6-W5	830-5	Report	Tufa	-	-
6	8-10-27-6-W5	820-6	Report	Tufa	-	-
7	11-36-27-9-W5	820-7	Report	Tufa	-	-
Drumheller 82P						
1	30-17-W4	Hand Hills	Deposit	Calc. Sediments, Marl	Submarginal-Poor	1.0 max.
2	1-12-26-24-W4	Serviceberry Creek	Showing	Tufa	Fair	0.2
3	1+2-6-31-26-W4	Stewart Lake	Showing	Calcareous Sediments	Submarginal	0.5
SOUTHERN ALBERTA						
Kananaskis Lake 82J						
1	13-35-16-5-W5	82J-1	Report	Tufa	-	-
2	1-15-21-9-W5	82J-2	Report	Tufa	-	-
3	10-28-22-7-W5	82J-3	Report	Tufa	-	-

Size (m3)	Overburden Thickness (m)	Road Access (km)	Site Conditions Moisture	Geographic Setting	Class
-	-	-	Wet, active spring	-	-
-	-	-	-	Bog and terraces	-
-	-	-	Wet, active seepage	-	-
-	-	-	Wet	Bog	-
-	-	-	Wet, active spring	Bog area	-
-	-	-	Wet	Bog area	-
-	-	-	Wet, active spring	-	-
-	-	-	Wet	Shoreline	-
-	-	-	Wet, active spring	Bog area	-
-	-	-	Wet	Bog area	-
-	-	-	-	Small terraces	-
-	-	-	Wet, active spring	-	-
-	-	-	Active spring	Terraces and mounds	-
-	-	-	Wet, active spring	Bog and terraces	-
Small	0	0.2	Wet, active spring	Hillside	A-1
Small	0-0.3	<0.2	Wet, active springs	Creek bottom	A-1
-	2.7-3.0	Roadside	Wet	Marshland	D-1
Moderate to small?	0	Roadside	Wet, active springs	Hillside	A-1
-	1.0	Roadside	Well drained	Flat to gently rolling	-
-	1.4	Roadside	Wet	Lake bed	B-2
-	-	Roadside	-	Hillside	-
-	0.5?	Roadside	Well drained	Flat to gently rolling	-
Moderate	1.5	<0.2	Wet	Marshland	D-1
-	0.6	0.2	Partially drained	Dried pond	B-2
-	-	-	Wet	-	A-1
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
-	Variable	0.8	Well drained	Upland hills	B-1
Insignificant	0	-	Wet, active spring	Hillside	A-1
Insignificant	0.5	Roadside	Well drained	Hillside	-
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

TABLE 10.
X-ray Diffraction and X-ray Fluorescence results - marl and tufa deposits

Deposit Name	X-ray Diffraction: Bulk (>3% in Abundance): Calcite	Aragonite	Quartz	Dolomite	Centrifuged (<3% in Abundance) (<2μm size): Montmorillionite	Illite	Chlorite	Kaolimite	Quartz	Calcite	X-Ray Fluorescence: Calcium	Iron	Manganese	Potassium	Titanium	Zinc	Silicon	Copper
Sturgeon Lake (T.H.6)	X	X	X		X						X	X	X	X	X	X		
Snipe Lake (T.H.8)	X	–	X		X	X		X	X	X	X	X	X	X	X	X	X	
Romeo Lake	X	–	X		X	X	X	X	–	–	X	X	X	X	X			
Smoky Lake (T.H.3)	X	–	X		X	–	–	–	–	–								
Halfway Lake (T.H.1)	X	–	X		–	–	–	–	–	–	X	X	X		X			
Evansburg	X	–	X		–	–	–	–	–	–	X	X	X					
Duffield																		
(outcrop F)	X	–	–		–	–	–	–	–	X	X	X	X					
(Testhole 13)	X	–	–		–	–	X	–	–	X	X	–	X					
(Testhole 21)	X	X	X		X	–	–	–	–	X	X	X	X	X	X		X	
Horseshoe Lake (Testhole 1)	X		X		–	–	–	–	–	–	X	X	X	X	X			
Big Lake (Testhole 2)	X		X		–	–	–	–	–	–	X	X	X					
Spruce Grove (Testhole 2)	X				–	–	–	–	–	X	X	X	X					X
Bon Accord (Testhole 6)	X	X	X		–	–	–	–	–	–	X							
Lac Brosseau (Testhole 4)	X	X	X		–	–	–	–	–	–	X	X	X	X				X
Lindbergh																		
(Testhole 2)	X	X	X		X	–	–	–	–	–	X	X	X	X	X	X	X	X
(Testhole 4)	X	X	X	X	X	–	–	–	–	–	X	X	X	X	X	X	X	–
(Testhole 11)	X	X	X		X	–	–	–	–	–	X	X	X	X	X	X	–	–
(Testhole 13)	X	X	X		X	–	–	–	–	–	X	X	X	X	X	X	X	X
(Testhole 16)	X	X	X		X	–	–	X	–	–	X	X	X	X	X	X	X	X
Marlboro (Testhole 1)	X	–	–		–	–	–	–	–	–	X	X	X					X
Hoadley	X		X		–	–	–	–	–	–								
Rose Creek	X		X		–	–	–	–	–	–	X	X	X		X			
Benalto											X	X						
(Testhole 3)	X		X		–	–	–	–	–	–	X	X	X					
Tees (Testhole C)	X		X		–	–	–	–	–	–	X	X	X		X			

TABLE 11

Chemical analyses of some Alberta Marl and Tufa deposits

DEPOSIT NAME	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	CaO	MgO	Na_2O	K_2O	CO_2	H_2O	LOI	Total
Grimshaw North (84C-2)	2.58	0.58	4.20	0.09	0.05	0.42	47.47	1.25	0.40	0.10	37.44	0.71	41.31	99.12
Sturgeon Lake (83N-3)	9.50	3.16	1.05	0.14	0.03	0.07	44.13	1.04	0.35	0.35	35.06	1.17	38.74	99.73
Snipe Lake (83N-5)	21.95	3.52	1.00	0.19	0.13	0.07	36.53	1.27	0.78	0.46	28.95	0.80	32.82	99.52
Smoky Lake (83I-3)	12.67	2.09	1.57	0.16	0.03	0.14	39.26	1.92	0.82	0.33	31.93	1.07	39.35	99.41
Romeo Lake (83J-3)	9.90	2.86	0.92	0.23	0.01	0.08	43.85	1.53	1.92	0.49	35.52	0.53	38.17	100.49
Halfway Lake (83I-4)	7.10	0.75	0.45	0.10	0.02	0.09	41.77	1.62	0.30	0.17	33.70	1.39	44.86	98.62
Marlboro (83F-3)	1.65	0.08	0.45	0.05	0.00	0.10	50.85	1.67	1.67	0.15	41.64	0.32	43.72	100.71
Evansburg (83G-2)	3.13	0.43	0.36	0.05	0.02	0.14	48.19	1.43	0.30	0.13	38.85	0.75	44.34	99.27
Horseshoe Lake (83H-1)	11.15	1.94	0.83	0.17	0.04	0.06	39.73	1.25	0.48	0.35	31.29	1.18	42.02	99.20
Big Lake (83H-5)	3.92	0.36	0.60	0.15	0.04	0.15	48.14	0.91	1.38	0.13	37.95	0.57	43.27	99.62
Spruce Grove (83H-11)	1.66	0.00	0.11	0.09	0.02	0.08	46.42	1.60	0.15	0.08	37.35	1.20	48.49	99.87
Bon Accord (83H-15)	8.65	1.02	0.75	0.11	0.11	0.08	38.12	1.36	1.02	0.21	29.58	2.13	45.21	98.77
Hoadley (83B-1)	1.55	0.19	0.37	0.12	0.00	0.03	47.35	0.97	0.27	0.07	37.35	1.24	46.62	98.78
Rose Creek (83B-4)	0.64	0.13	0.13	0.04	0.00	0.03	52.34	0.77	0.44	0.08	41.85	0.53	44.83	99.96
Benalto (83B-7)	4.14	0.41	0.63	0.11	0.02	0.19	46.90	1.22	0.57	0.17	37.53	0.76	43.81	98.93
Tees (83A-1)	7.92	0.83	0.33	0.03	0.04	0.08	44.10	1.15	0.62	0.21	35.03	1.17	43.04	99.80
Lac Brosseau (73E-1)	9.73	0.61	0.69	0.10	0.04	0.07	39.03	0.45	1.15	0.16	29.88	2.28	45.74	100.05
Ponoka Limestone	44.18	0.08	0.15	0.01	0.12	0.15	29.25	0.35	0.22	0.03	?	0.23	24.17	98.94
Duffield (83G-9)														
Outcrop F	0.40	0.11	0.38	0.09	0.01	0.12	51.29	1.50	0.53	0.04	41.55	0.36	44.69	99.52
Testhole 13	0.16	0.10	0.07	0.02	0.02	0.18	52.55	1.36	0.61	0.04	41.68	0.29	44.82	100.22
Testhole 21	14.07	3.51	1.24	0.21	0.07	0.14	34.84	1.64	1.04	0.55	26.72	2.08	39.35	98.74
Lindbergh (73E-2)														
Testhole 2	24.65	4.88	2.19	0.30	0.06	0.11	32.29	1.86	0.98	0.71	25.98	1.17	31.05	100.25
Testhole 4	30.98	5.61	1.98	0.29	0.14	0.07	26.41	1.75	1.40	0.85	21.03	1.56	28.69	99.73
Testhole 11	11.07	2.65	1.07	0.16	0.03	0.05	42.90	1.33	0.54	0.36	33.75	1.20	38.29	99.65
Testhole 13	16.37	3.31	1.45	0.27	0.04	0.09	37.59	1.59	1.31	0.54	29.77	0.99	36.30	99.85
Testhole 16	20.67	5.52	1.38	0.36	0.00	0.09	34.97	2.12	0.76	0.18	28.09	1.36	32.52	99.93

PART III

CONCLUSIONS

ECONOMIC

Very large marl and tufa deposits are not abundant in Alberta; however, the Duffield, Halfway Lake, Big Lake-Atim Lake, Bon Accord, and Lindbergh deposits each contain half a million cubic metres or more of marl. Together, they contain about 8.5 million m^3 of a total estimated 10 million m^3 of marl and tufa in the province. The following deposits are intermediate to large in size (50 000 m^3 to greater than 150 000 m^3); Sturgeon Lake, Snipe Lake, Grimshaw, Horseshoe Lake, Deposit B (83H), Marlboro, Benalto, and Raven. Most deposits in Alberta are small to intermediate in size (< 10 000 to 50 000 m^3). Table 9 provides details on all deposits.

Some of the acid soil areas in the Peace River area can be treated using marl deposits, if existing deposits are developed. Liming requirements can be met in the western and north-central regions of the province using local marls. The large area of acid soils in east-central Alberta would require transporting marl over 160 km from deposits to the west or north. The Hand Hills deposit contains calcareous sediments and muddy marls that are unsuitable for treating acid soils.

GEOLOGIC

The potential for future discoveries of marl in the Peace River area is very low.

In the central part of the province, potential for future discoveries of marl is probably best in the area west of the fifth meridian.

Some potential exists west of the fourth meridian, but north of latitude 53°30′, north and northeast of Edmonton.

The deposits investigated as well as ones reported are shown on Figure 38 and represent an inventory of all the known marl and tufa locations. Table 9 summarizes information that is known on these deposits.

The abandonded channel (D), seepage-ponded (B-2) and spring-fed lake (A-2) classes produced the largest and, hence, the most economically attractive deposits. The hillside spring (A-1), spring-mound (A-2), hillside-seepage (B-1), and shoreline fringe (C) classes produced small to intermediate deposits. The Recent backswamp (E), Recent lacustrine calcareous sediments (F), alkali flats (G), and preglacial (H) classes are generally of no economic importance.

Tufa deposits are abundant west of the fifth meridian, where the Paskapoo Formation forms bedrock. Marl deposits in central Alberta are confined to west of the fifth meridian and west of the fourth meridian - north of latitude 53°30′. Marl deposits in the Peace River area are rare and scattered, with no recognizable pattern of distribution.

The deposition of marl and tufa was found to depend on the presence of initial source carbonates, leaching of this source material, transportation of Ca^{+2} and HCO_3 ions, discharge at the surface, and reprecipitation of $CaCO_3$. This process is influenced by climate, transmissivity of the sediments, topography, length of groundwater flow system, and mechanisms that cause precipitation of $CaCO_3$.

The term "marl" should be restricted to a "freshwater, fine-grained, friable, light-colored limestone that contains greater than 50 percent C.C.E." The major components in marl are nearly always calcite and minor amounts of SiO_2. Clay minerals seldom exceeded 5 percent of the sample. Gypsum and aragonite are only occasionally found. Organic material was found to be the other main contaminant. In most cases, organic material was less than 20 percent and SiO_2 was less than 25 percent. The SiO_2 component was classed as mud, although large amounts of diatoms were present in some samples.

Petrologically, the marls consist primarily of micrite with varying amounts of fossil gastropods, pelecypods, diatoms, ostracods, and *Chara* sp. remains. The tufa groups shows a range in crystal size from micrite to sparry calcite (about 2 μm to 40 μm). Fossils are rare, except for molds of moss and plant remains.

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APPENDIX 1: FACTORS INVOLVED IN THE DEPOSITION OF MARL AND TUFA

CLIMATE

A cool, moist climate and a spruce forest vegetation cover likely provides the maximum amount of carbonic acid production in the root zone, to be available for leaching source carbonates (Wallick, pers. comm.). A minimum of carbonic acid is probably produced in a dry region with a grassland vegetation.

Where mean annual precipitation exceeds evapotranspiration, strong continuous groundwater flows can be expected, which enhances the chances of thick marl deposits being formed in areas of groundwater discharge. If evapotranspiration greatly exceeds mean precipitation groundwater discharging into basins will not form permanent lakes and crusts of salts are generally the only expression of carbonate deposition. Carbonate precipitation will not occur at temperatures below freezing.

CARBONATE SOURCES AND RECHARGE AREAS

In Alberta, there are two major sources of carbonate in groundwaters, glacial drift and bedrock. Glacial till is not a good source of carbonate ions for several reasons. The total amount of carbonate available for leaching is small, 0 to 15 percent (Pawluk and Bayrock, 1969). High clay content results in a very slow infiltration rate by surface water and sluggish groundwater flow, which in turn results in little water being available to leach the till. Slow water movement allows dissolved Ca^{+2} ions to be exchanged for Na^{+} ions. Glaciolacustrine silt and clay deposits are also not considered good carbonate sources for the same reasons.

Thiel (1930), in a study of distribution of marl deposits in Minnesota, found texture of material in groundwater recharge zones to be more important in influencing marl deposition than carbonate content of the material. Areas with coarse-textured recharge areas tended to contain more and larger marl deposits than areas with fine-textured recharge areas, even if the fine-textured areas contained more original carbonate. Outwash sands, kames, eskers, glaciofluvial sands, and similar materials are good recharge areas and fair sources of carbonate in Alberta. These areas are well suited to providing carbonate for marl deposition because of their high permeability and low clay content.

TOPOGRAPHY

Topography affects the rate of groundwater movement as well as the type of flow system that will develop. High local relief tends to produce local and intermediate flow systems with high hydraulic head and rapid water movement. Low relief tends to produce sluggish, more regional, groundwater flow.

In Alberta, marl has been deposited in locations with strong continuous flows of groundwater from local flow systems.

GROUNDWATER AND AQUIFERS

The chemical evolution of groundwater with respect to $CaCO_3$ is determined by root zone factors, length of the flow system, cation exchange processes, and sulfate reduction processes. Most shallow groundwaters in Alberta that are predominantly Ca^{+2} HCO_3^- are also thought to be saturated with respect to $CaCO_3$ (Wallick, pers. comm.).

Length of the flow system determines how long the water is exposed to chemical altering processes. Cation exchange takes place mainly on clay minerals whereby absorbed Na^{+} ions are replaced with Ca^{+2} ions from the groundwater solution. Sulfate reduction is a process whereby certain varieties of bacteria living in anaerobic environments cause SO_4^{-2} to be reduced to H_2S (gas) + HCO_3^- in an aqueous medium. In addition to HCO_3^-, when carbonate rocks are available (Hem, 1959), CO_2 is often added to the groundwater, which tends to keep $CaCO_3$ in solution.

Cation exchange and sulfate reduction reactions occur most readily in clay-rich bedrock aquifers, such as the Wapiti Formation, and in till or glaciolacustrine sediments, which are also clay rich.

These reactions are not as common in waters moving through the Paskapoo Formation or coarse-grained surficial sediments. This allows carbonate to leach from the sediments and to build up in waters in these coarse-grained sediments. The carbonate leaching and transporting ability of these coarse sediments is also enhanced by the rapid movement of groundwater through them. For these reasons, Paskapoo Formation and coarse-grained surficial aquifers are more conducive to marl and tufa deposition.

Location and Type of Groundwater Discharge

Hillside springs usually produce a tufa or tufaceous marl, whereas a hillside seepage usually produces marl, as does precipitation in most lake and pond settings. Tufa nodules are occasionally found within marls from lakes and probably represent deposition at a time when groundwaters were discharging into an aqueous subaerial environment. Very diffuse seepage into an evaporating lake basin produces fine-grained $CaCO_3$ mixed with other salts.

Surface Conditions

Once groundwater is discharged at the surface several factors begin to influence $CaCO_3$ equilibrium. At a hillside spring, reduced pressure of CO_2 in the water upon release, surface aeration of waters as they tumble down steep slopes, increased surface temperatures, and certain algae all cause a loss in CO_2, which upsets carbonate equilibrium. The effect in all cases is to precipitate $CaCO_3$ in order to re-establish chemical equilibrium. Temperature and aeration may be the more important processes at such a setting.

At a subaerial seepage site the rate of groundwater discharge is likely to be smaller than at a spring; however, more of the water will be exposed to the atmosphere immediately upon discharge. This discharge will result in a rapid precipitation of fine-grained micritic marls (Folk, 1974) brought about by the rapid aeration, temperature increase, and loss of dissolved CO_2 gas by the discharging water. The size of such deposits is probably restricted because the moist environment produces a spruce forest, which in turn produces an acidic soil and a resulting $CaCO_3$ dissolving environment. Deposit size will be determined by the balance between precipitation and solution of the marl. Subaerial seepage deposits are very important because they illustrate the fact that marl can form in environments other than lakes or ponds and the removal of CO_2 can almost certainly go on in an apparently strictly physico-chemical manner without the influence of *Chara* algae.

In a lake or pond setting, the algae action may promote marl precipitation in addition to the effects of factors that act in the subaerial environment. Wave action is also particularly important in aerating the water.

If marl is being precipitated at a lake, several factors control whether or not marl will accumulate. These include:

A. Lake basin depth

In a very deep lake, $CaCO_3$ precipitating in the epilimnion will likely be redissolved at greater depths due to increased CO_2 content with depth (Roddick, 1970).

Current action may also cause dispersal into deeper waters where the marl is dissolved. In shallower lakes with moderate current action, precipitating marl may be drawn out into spits, bars, and shoals.

B. Lake size

A very large lake is likely to have wind-induced currents that may disperse, over the entire lake, any marl formed near shore.

Large lakes are also likely to be deep, and may not accumulate marl. Also, algal colonies that thrive in shallow quiet water may not develop. Shoreline fringe deposits may occur, however, in shallow sheltered bays.

C. Lake drainage

Lake basins with a well-defined outlet and a rapid throughput of water are not favorable for marl production. Rapid water change may keep carbonate

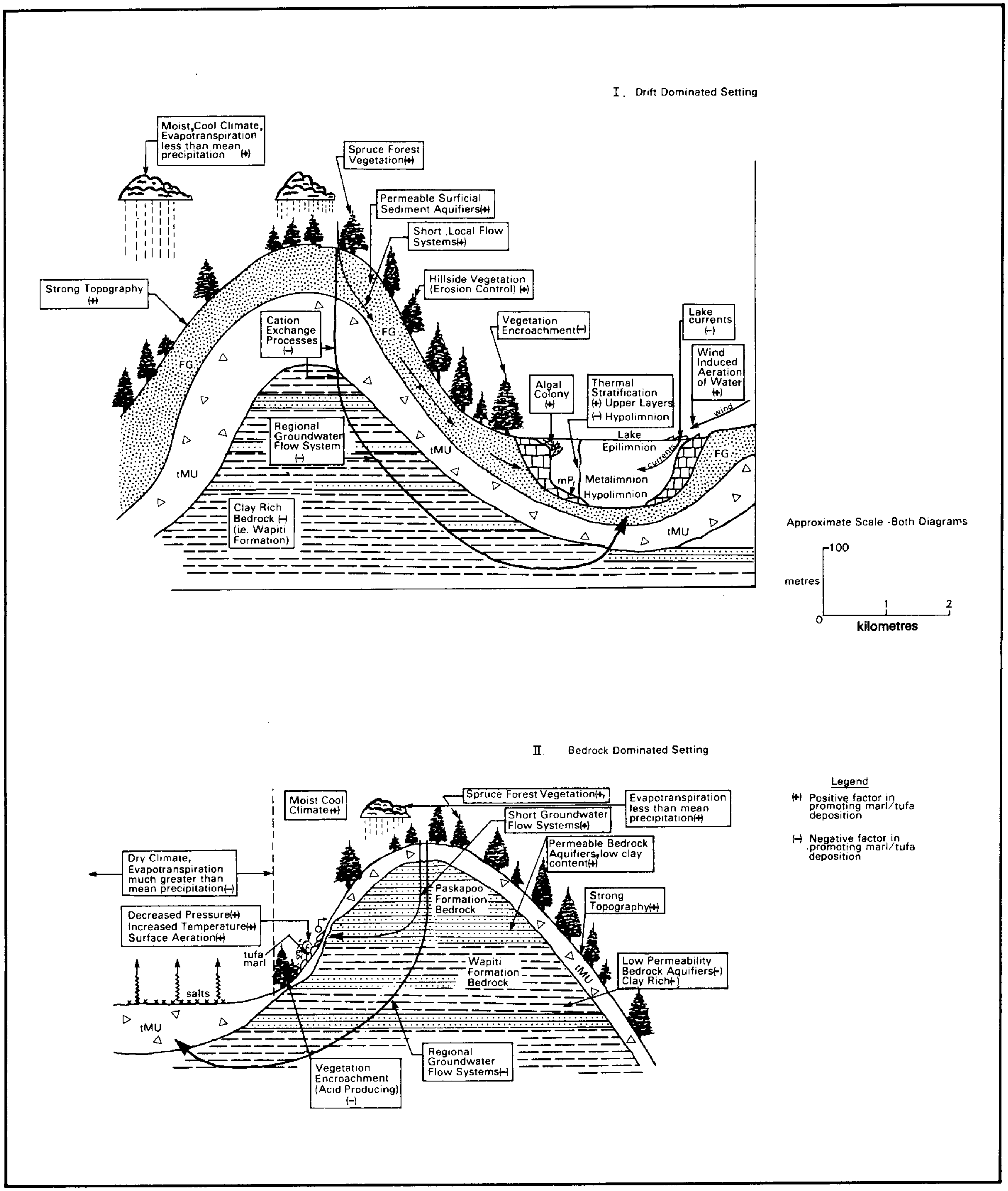


FIGURE 36. Major factors involved in marl and tufa deposition.

concentrations low, preventing marl precipitation. Marl that is precipitated may be dispersed and rapid water movement discourages the growth of algal colonies. Most marl deposits currently active in Alberta are in poorly drained, fairly stagnant water bodies.

D. Vegetation encroachment

As long as groundwater can keep a lake very alkaline, the surrounding vegetation will generally not grow over the lake. Should the supply of groundwater be interrupted, or the chemistry changed for a sufficient length of time, plant succession processes of lake infilling become dominant. Calcium carbonate ceases to be deposited, and peat deposits are produced. The fact that many active marl deposits in Alberta rest on glacial materials and some marl deposits are quite thick, suggests a continuous supply of alkaline waters since deglaciation in these areas.

E. Vegetation as erosion control

The more vegetation that establishes itself on upland areas and slopes, the less clastic sedimentation will occur in adjacent lake basins. High clastic sedimentation rates into a basin will generally inhibit marl accumulation.

Figure 36 attempts to show the major factors involved in all of the marl/tufa development processes. Positive and negative symbols indicate whether the factor is a positive or negative one in the eventual formation and preservation of a marl or tufa deposit. The lower diagram shows a Paskapoo bedrock hillside depositional site and the upper a "Wapiti type" formation bedrock, lake site.

APPENDIX 2: DISTRIBUTION AND EVOLUTION OF MARL DEPOSITS IN ALBERTA

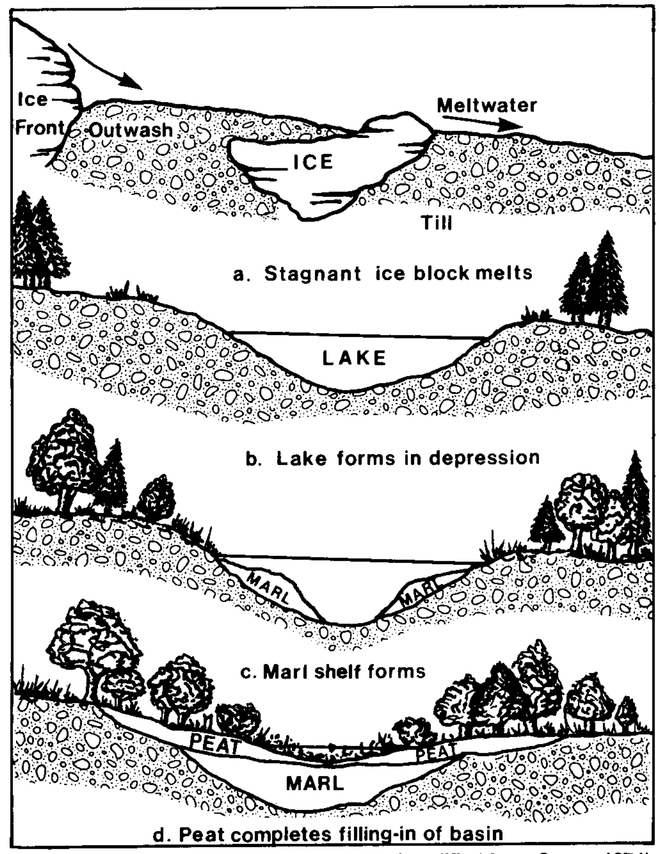
Figure 38 shows the locations and distributions of marl and tufa deposits in Alberta. By comparing the distribution of active deposits to soil zones, the vast majority of deposits are seen to be found in the "Gray Wooded," "Dark Gray Wooded," and "Black" soil zones of Alberta (Odynsky, 1962). These zones are characterized by annual precipitation of 43 to 61 cm (17 to 24 in) with the higher values closer to the mountains; 25 to 46 cm (10 to 18 in) of this total annual precipitation falls as rainfall from April to August, the time of year that the groundwater can be recharged. Evapotranspiration is between 36 and 46 cm (14 to 18 in) annually (Government of Alberta and University of Alberta, 1969) for this same area, which suggests that evapotranspiration is currently slightly less or equal to annual precipitation in these areas. These soil zones are typically parkland to spruce forest vegetated.

In eastern Canada, where annual precipitation generally exceeds evapotranspiration, many more marl deposits are actively forming than in Alberta (Guillet, 1969; Waddington, 1950). When annual precipitation exceeds evapotranspiration, the groundwater can be recharged more continuously, hence marl depositional sites receive a constant supply of groundwater. Climate is, therefore, seen as a major factor in determining the distribution of marl and tufa deposits.

Camp (1974) proposed several stages of development in typical marl lakes in Michigan (Fig. 37). The melting of stagnant ice blocks, which became trapped in till or outwash and then covered with outwash, resulted in moderately deep lakes forming which intersect the water table (stage B, Fig. 37). A constant supply of Ca^{+2} HCO_3 ions from the leaching of the outwash and till was assured. Marl first forms as shelves along the shallower portions (stage C, Fig. 37) of the lakes. If the supply of groundwater is maintained and the lake is not extremely deep, the marl shelves will gradually build out until they completely fill the lake. As the marl shelves are forming outward, terrestrial vegetation begins to develop on the shallow portions of the marl shelf. This hydroseric succession keeps pace with the marl shelf-building processes, eventually covering the marl and forming a peat bog (stage

D, Fig. 37). This process can be interrupted at any time by changes in any of the factors discussed in Appendix 1. This model of marl formation may explain many of Alberta's marl deposits. Many of the seepage-ponded (B-2) deposits are commonly associated with outwash in low areas and often the lakes have vegetation enroaching on them. These deposits may be presently between Camp's C and D stages. Some actively precipitating shoreline-fringe deposits show similar shelves around lakes and likely represent a Stage C setting (Fig. 37). The inactively precipitating shoreline-fringe deposits represent deposits which could not proceed beyond the stage C development. Camp's model does not apply to the class A-1, A-2, A-3, B-1, D-1, or D-2 deposits described in this report.

The overwhelming majority of lake marl deposits in Alberta seem to be in the final, near final, or finished stages of development. Marl precipitation was rapid, and then ceased, during the Altithermal period (9000 to 7000 years B.P.) at the Duffield deposit (Hillerud, 1966). Marl precipitation may have flourished in the province north of about 53° latitude and west of about 114° longitude during this same time. The close of the the Altithermal period brought a cool, dry climate and spreading grasslands, which may have been the important factor in retarding or ceasing marl deposition in the province.



(modified from Camp, 1974)

FIGURE 37. Stages of development of a typical marl lake

APPENDIX 3: THE ABSENCE OF MARL DEPOSITS IN EAST-CENTRAL ALBERTA

The absence of marl deposits in east-central Alberta, south of about latitude 53° and east of longitude 114° can be explained by several factors. At present east-central and southern Alberta has a grassland vegetation. Wallick (in prep.) in a study of sodium sulfate deposits at Horseshoe Lake[1] concluded that this area was very warm and dry during the Altithermal, with grassland replacing spruce forests. Ritchie (1976) suggests that the grassland environment may have been present south of 53° latitude from as early as 9500 B.P. A grassland vegetative cover, regardless of climate, is not likely to produce the quantity of "carbonate leaching" acids that a spruce forest cover does, hence marl deposits are not expected. A grassland cover with a warm, dry climate, decreases even more the likelihood of marl deposits forming. This is due to evapotranspiration exceeding annual precipitation which causes: (1) most lakes to dry up seasonally, forming only salt flats; (2) lakes that do not dry up are often recharge areas in the spring and fall, discharge areas during the summer, and hydrogeologically inactive during the winter (Hackbarth, 1975). A continued supply of calcium bicarbonate ions for marl precipitation is not assured[2]; (3) recharge to the groundwater is often slow and in small amounts; (4) groundwater flow systems change from marl depositing, short, local ones, to unfavorable deeper ones, as the water table drops. Since a grassland environment probably existed south of 53° since about 9500 B.P., "paleo" marl deposits may have formed before 9500 B.P. and been covered by later sediments. As none of these "paleo" deposits were encountered during this study, conditions before 9500 B.P. may not have been favorable either for marl precipitation.

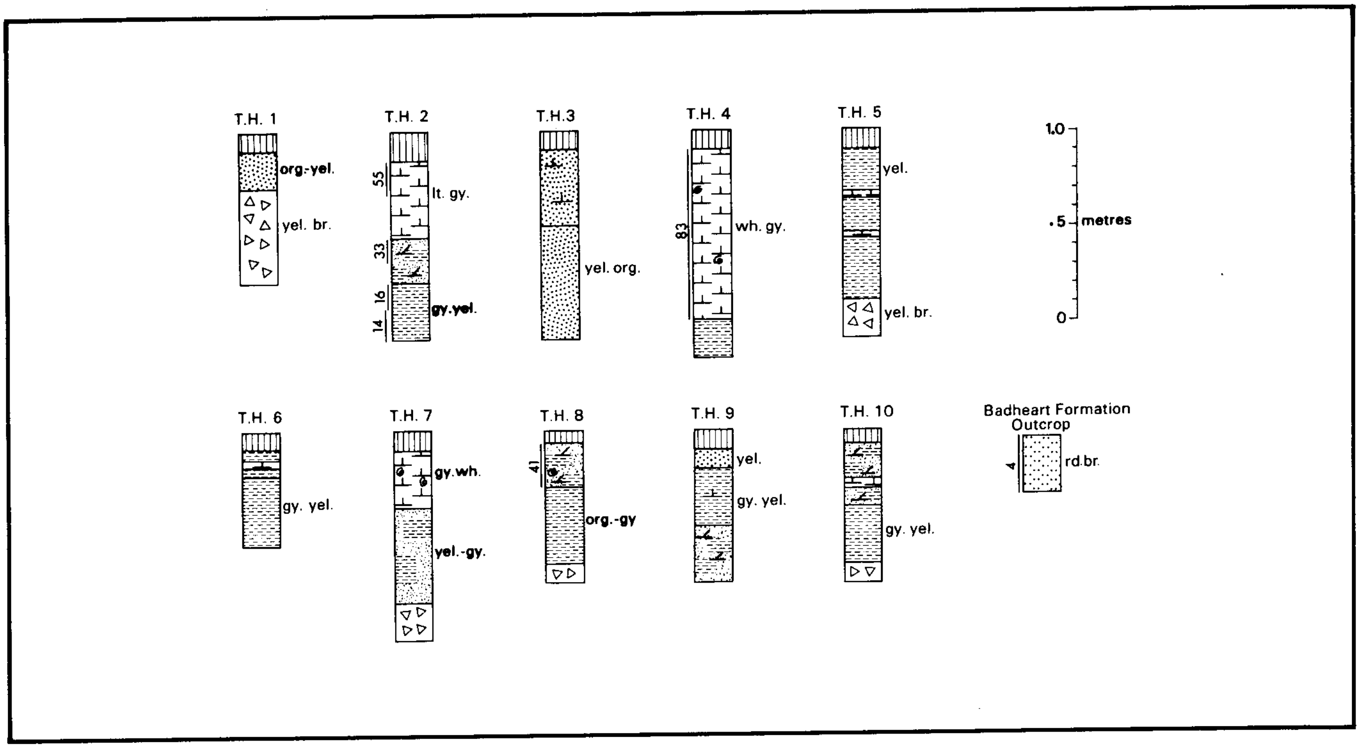
This period (before 9500 B.P.) according to Wallick (in prep.) was a warming, wet period with high clastic sedimentation rates due to the lack of a well-developed vegetative cover in the Horseshoe Lake area. If these conditions had been present over much of east-central and southern Alberta, the leaching of source carbonates might have been very effective; however, the high clastic sedimentation rates may have inhibited the formation of thick, high-quality marl deposits.

[1] Located 45 km (32 mi.) south of Wainwright, Alberta - south of 53° latitude

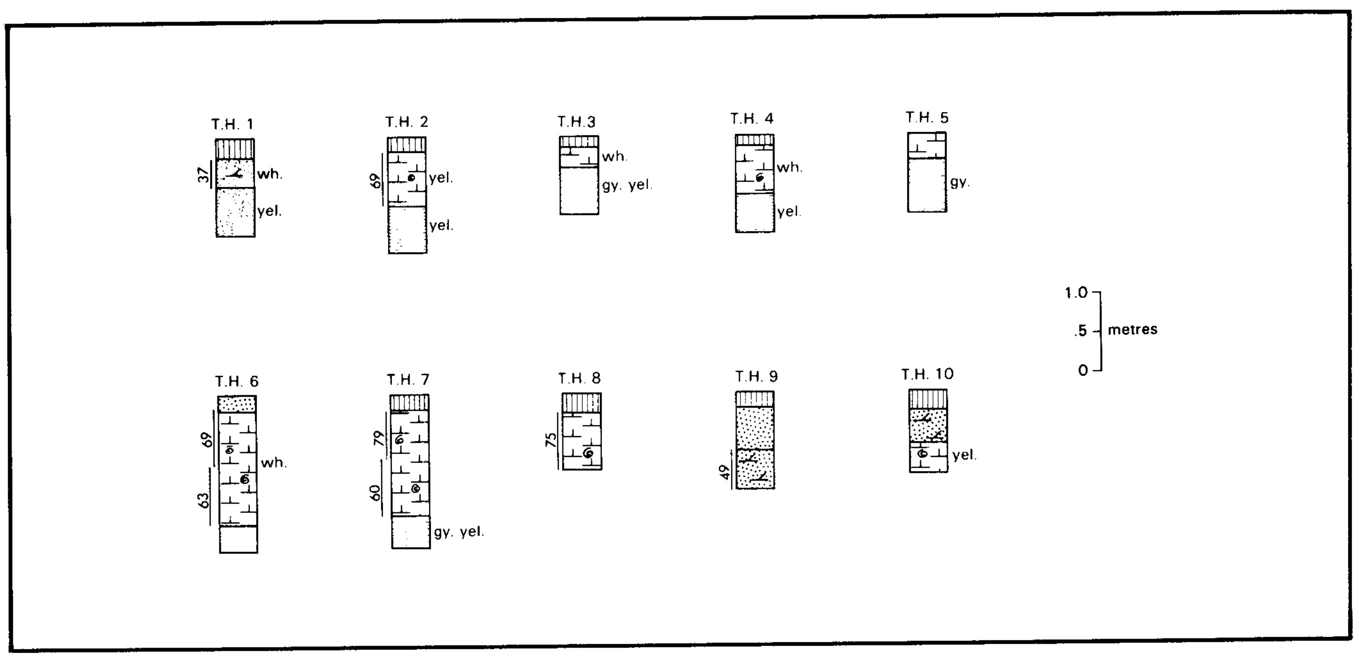
[2] Interestingly, shallow drift waters at the present time are largely Ca^{+2}, Mg^{+2}, HCO_3^-, or CO_3^{-2} throughout much of east-central Alberta. The groundwater chemistry at least is potentially right for marl deposition.

APPENDIX 4: TESTHOLE DATA–SPIRIT RIVER DEPOSIT

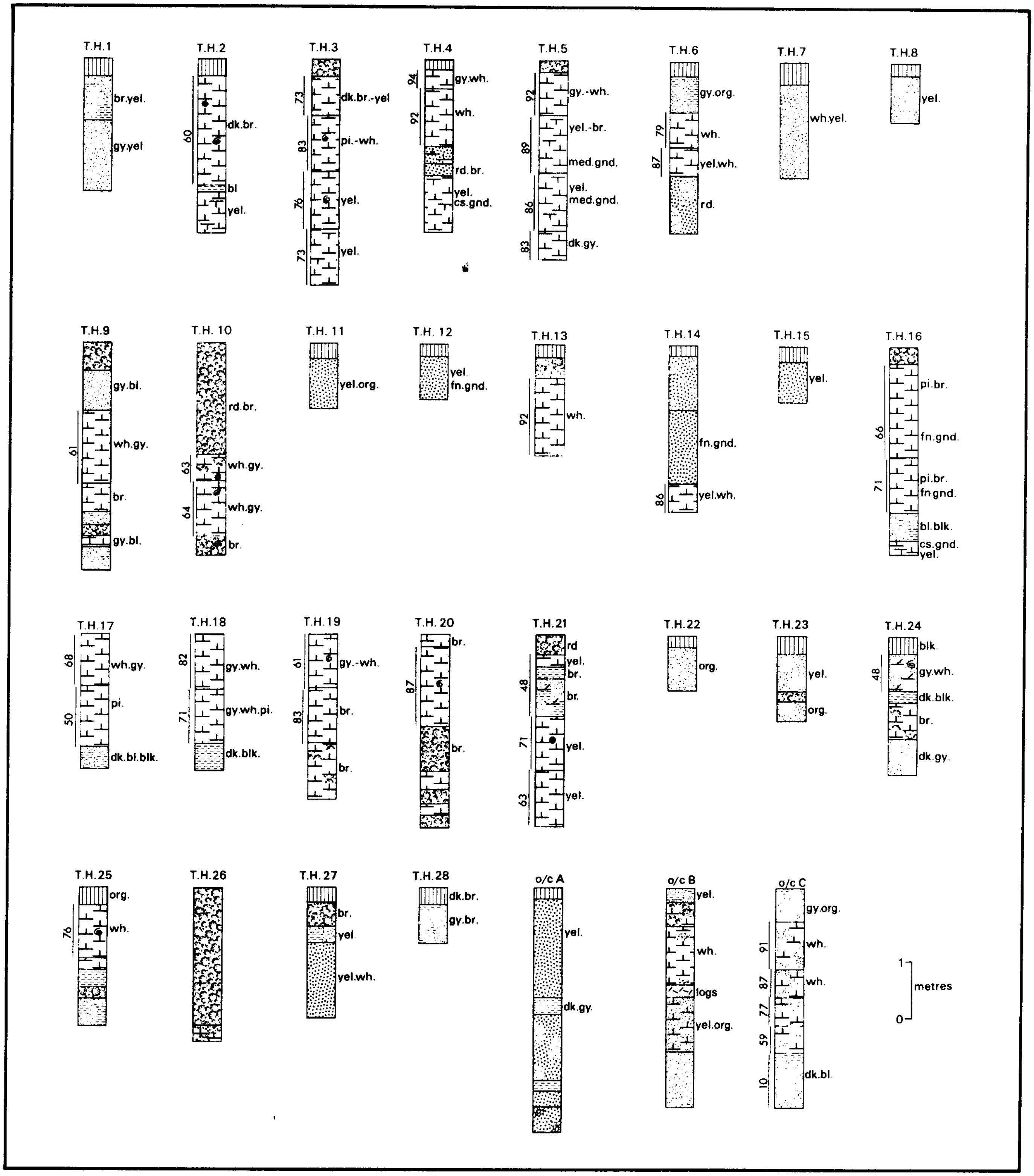
(see Appendix 10 for legend)



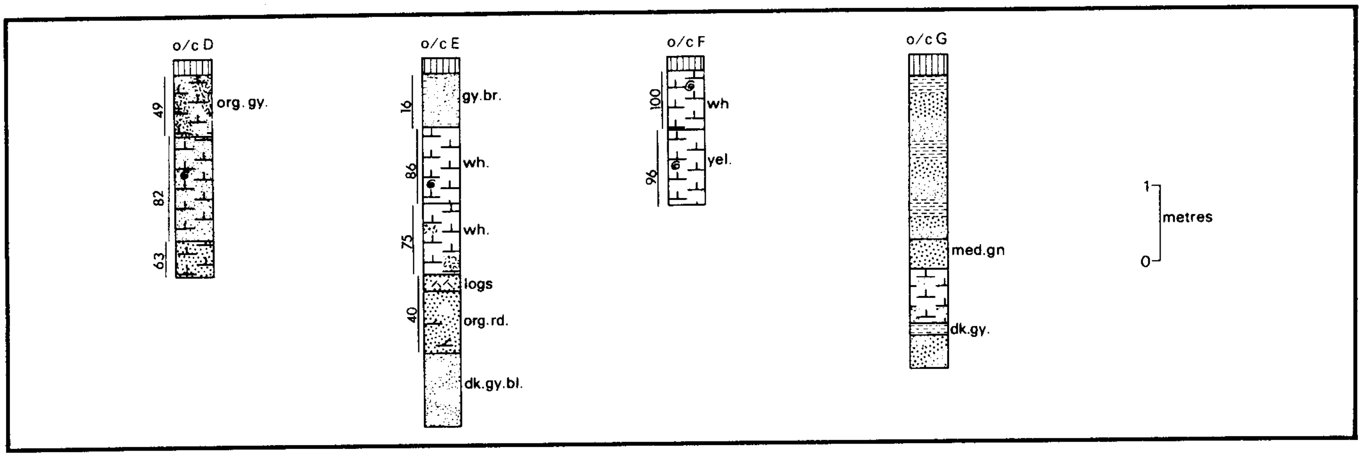
APPENDIX 5: TESTHOLE LITHOLOGIES AND DESCRIPTIONS – SNIPE LAKE DEPOSIT



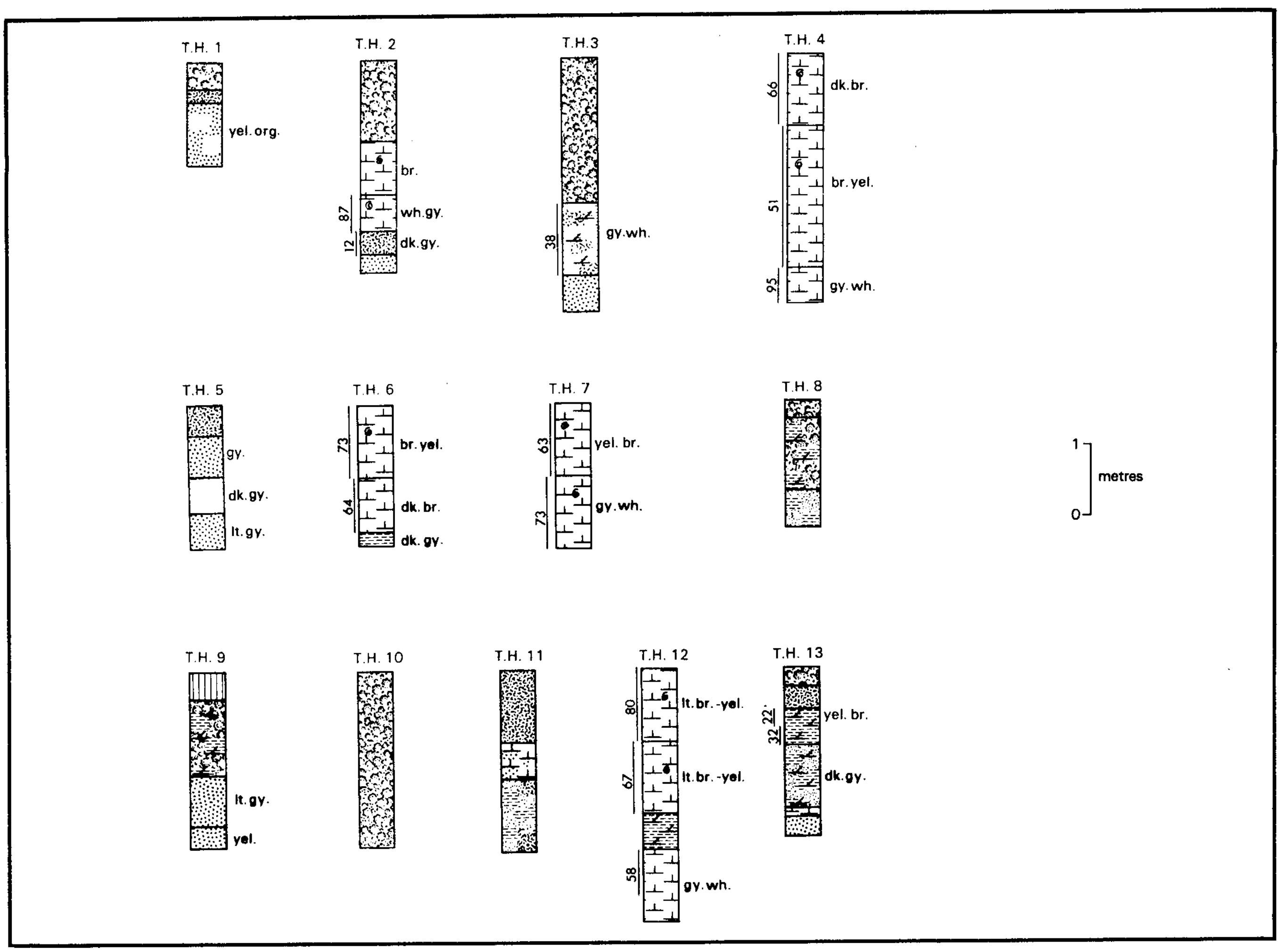
APPENDIX 6: TESTHOLE LITHOLOGIES — DUFFIELD DEPOSIT



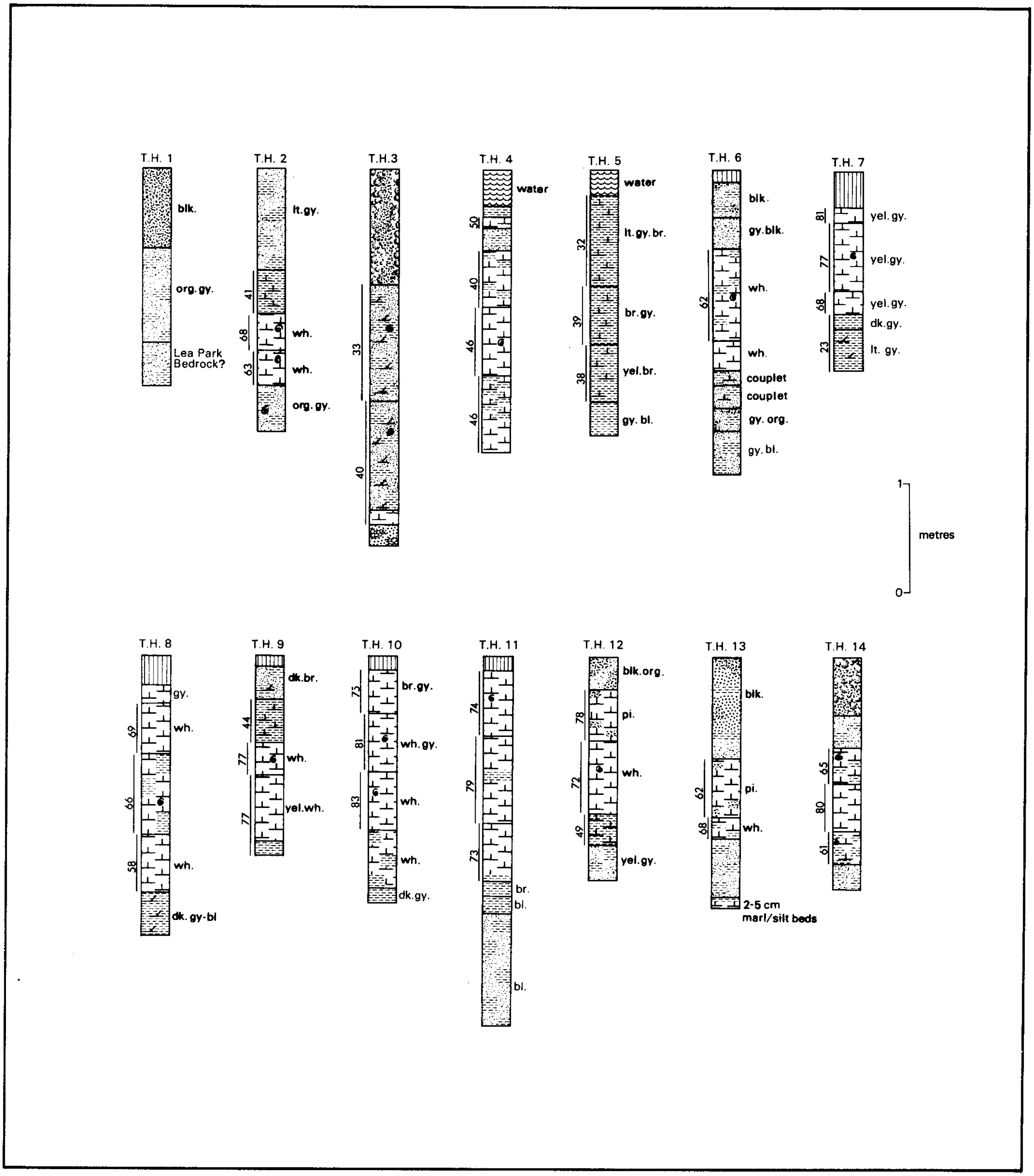
APPENDIX 6: (continued)



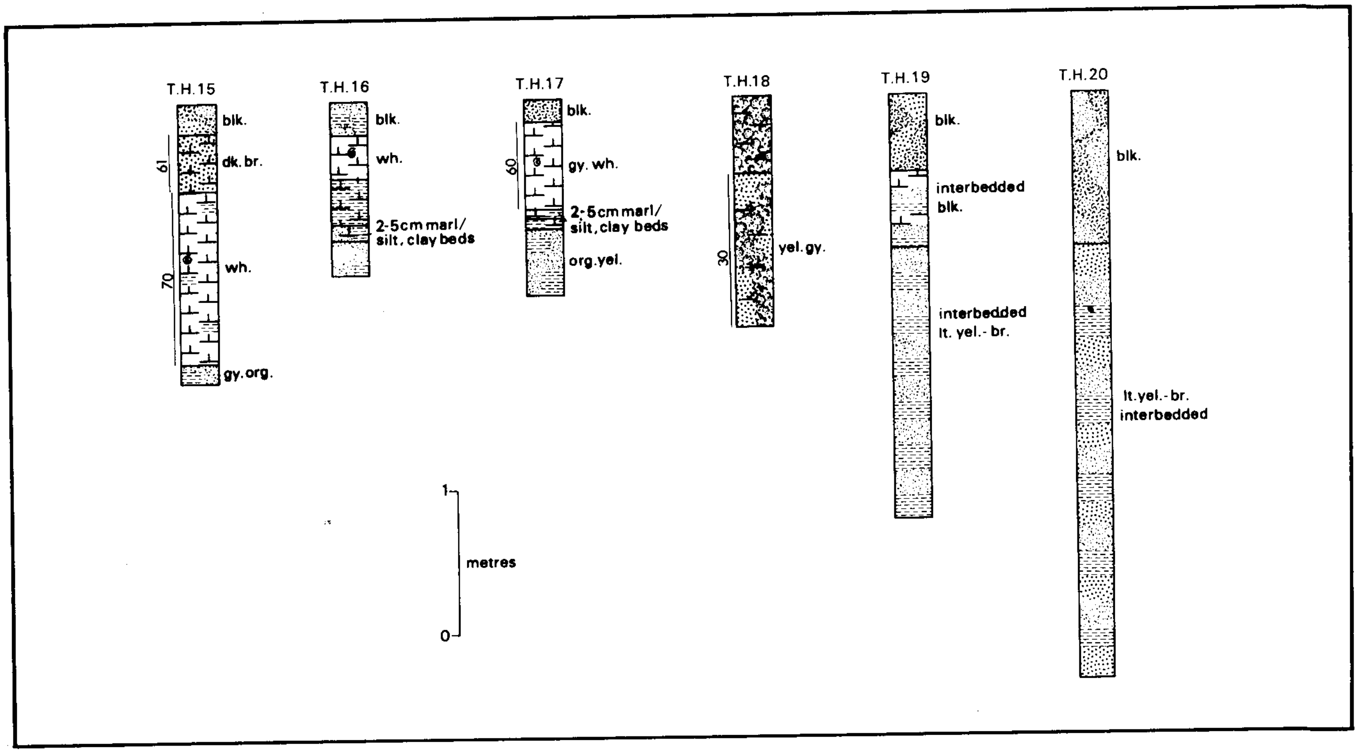
APPENDIX 7: TESTHOLE DATA — BON ACCORD DEPOSITS



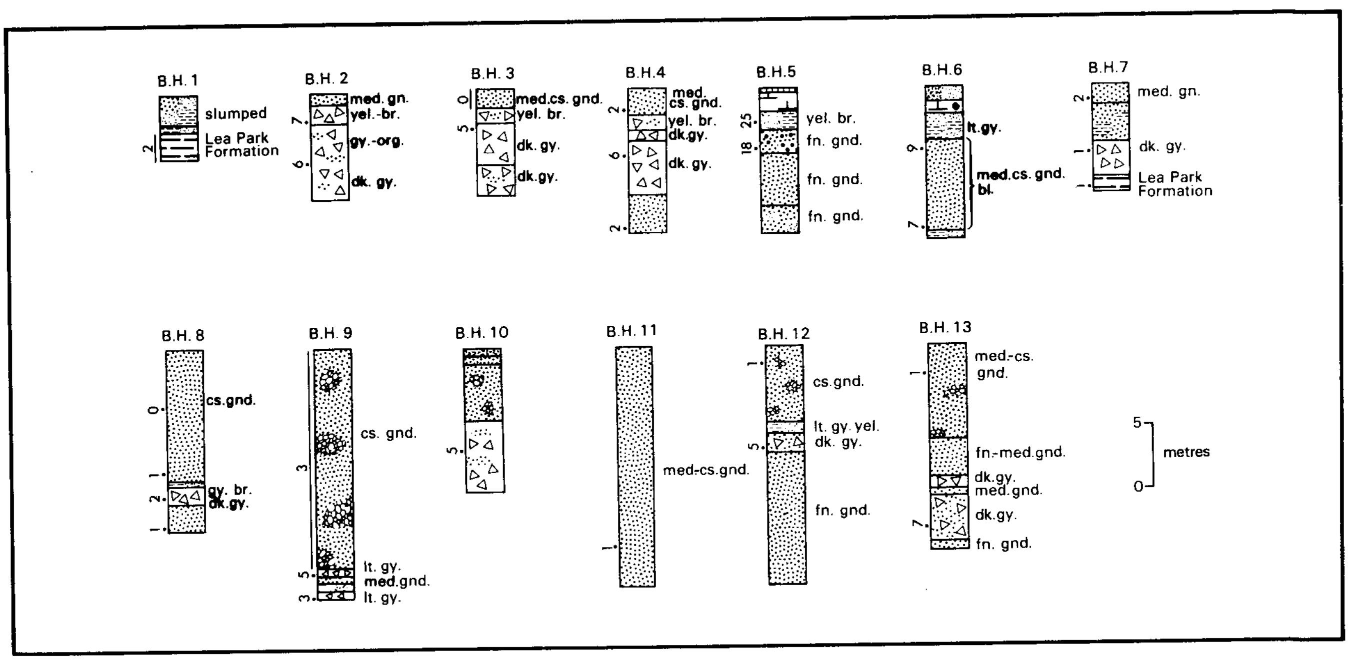
APPENDIX 8: SHALLOW TESTHOLES — LINDBERGH DEPOSIT



APPENDIX 8: (continued)



APPENDIX 9: DRY AUGER BOREHOLES — LINDBERGH AND VICINITY



APPENDIX 10: LEGEND FOR MAPS AND TESTHOLE DATA

A combination of letters and numbers is used to describe each map unit. The lowercase letters preceding the capitals (if present) indicate the composition of the unit. The first uppercase letter indicates the genetic class. The next uppercase letter (or up to two letters) indicate the genetic modifer, providing any additional information about the genetic class. The next lowercase letter indicates the morphology of the unit. Following this is a number that indicates relief. Following this number, a lowercase letter indicates thickness of the unit, if specifically known. If not specified by this last letter, all units are generally greater than one meter thick.

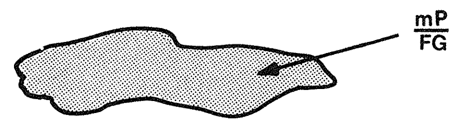
Where two units overlie one another, the letter-number combinations are separated by a horizontal bar.

e.g. $\frac{\text{Unit 1}}{\text{Unit 2}}$

Single units that are composed of varying amounts of two predominant genetic classes are treated thus:

X||Y: unknown proportions of genetic classes X and Y; X overlies Y
X//Y: 25% X, 75% Y; with X overlying Y
X/Y: 50% X, 50% Y, X over Y
X\\Y: 75% X, 25% Y; X over Y

Marl and tufa deposits are also shaded, in addition to a symbol:



Composition[1]
- g - gravel
- s - sand
- $ - silt
- c - clay
- f - silt and clay
- t - till
- sh - shale
- p - peat
- mk - muck[2]
- n - tufa
- m - marl (>50% C.C.E.)
- mt - marl and tufa
- d - calcareous (20-49% C.C.E.)
- u - undifferentiated[3]
- co - coal
- h - hematitic
- ss - sandstone

Genetic Class
- O - organic
- C - colluvium
- F - fluvial
- E - eolian
- L - lacustrine
- M - moraine
- P - chemically precipitated
- R - bedrock

Genetic Modifier
- W - Wapiti Formation
- L - Lea Park Formation
- B - Badheart Formation
- P - Paskapoo Formation
- E - eroded
- G - glacial
- R - modern or recent
- U - undifferentiated
- BC - buried channel
- C - meltwater channel
- K - kame
- Δ - delta
- B - bedded

[1]When two or more composition modifers are listed, they are listed in decreasing order of abundance.

[2]Decomposed, dark-colored, organics mixed with fine grained (silt/clay) clastic material.

[3]Absences of a composition letter also indicate undifferentiated.

Morphology
- f - fan
- h - hummocky; hills and hollows, roughly equidimensional
- l - level
- m - rolling; alternating concave and convex morphologic elements, length to width ratio of more than 2, parallel to non-oriented.
- p - pitted; relatively flat area having prominent depressions or pits.
- d - dunes
- t - terrace
- te - erosional terrace
- td - depositional terrace
- v - veneer; less than 1 m thick

Relief
- 1 - local relief less than 3 m
- 2 - local relief 3 to 9 m
- 3 - local relief greater than 9 m

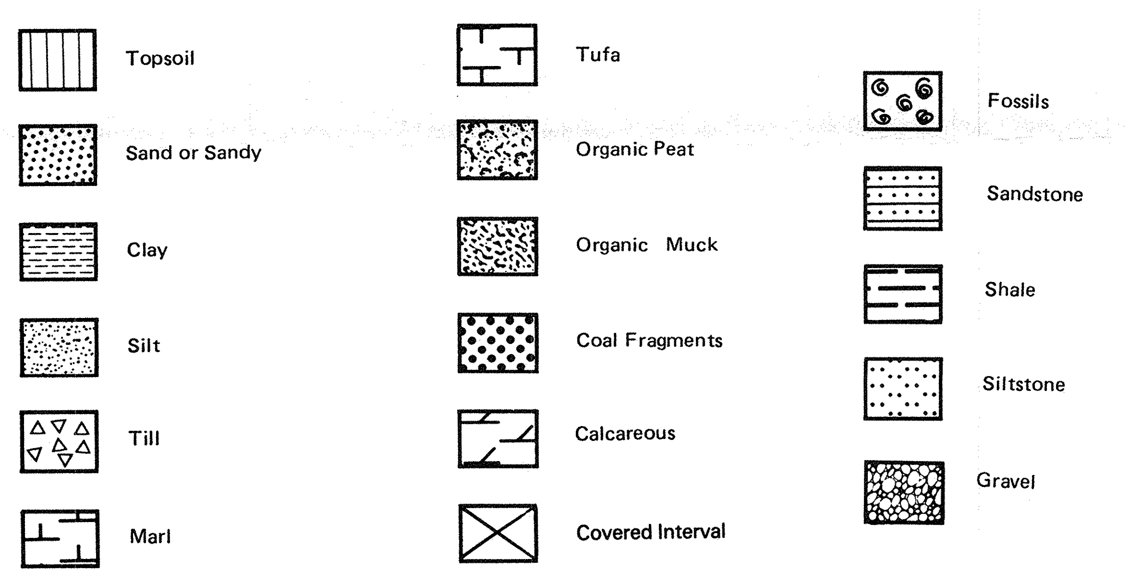
Thickness
- a - less than 3 m
- b - 3-7 m
- c - 7-20 m

example:

a) $\frac{\text{pO//dmkO}}{\text{sgFGl1a}}$

pO//dmkO ← peaty organics 25% overlying calcareous muck organics; both overlie the lower unit.
sgFGl1a ← glaciofluvial sand and gravel, level, <3 m relief, <3 m thick.

TESTHOLE AND CROSS-SECTION LEGEND



93| Sampled interval and C.C.E. value obtained. 93 • Grab sample and C.C.E. value obtained.

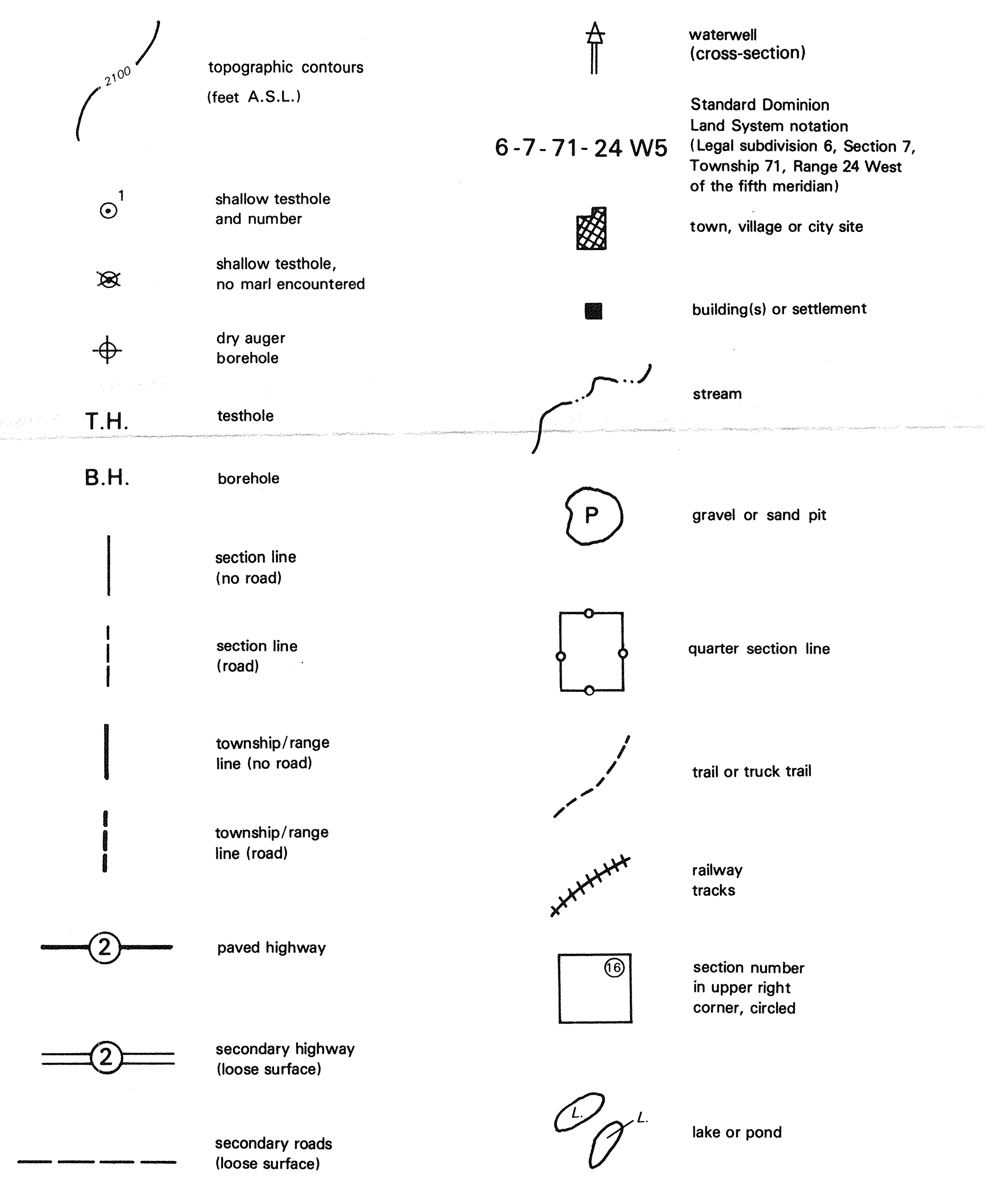
Other

lt -	light
dk -	dark
calc -	calcareous (20-49 % C.C.E. estimate)
cs -	coarse (0.5-1 mm)
med-	medium (0.25-0.5 mm)
fn -	fine (<0.25 mm)
fn - med	fine to medium (<0.25-0.5 mm)
sd -	sand
gnd -	grained
X-bd -	x-bedding present

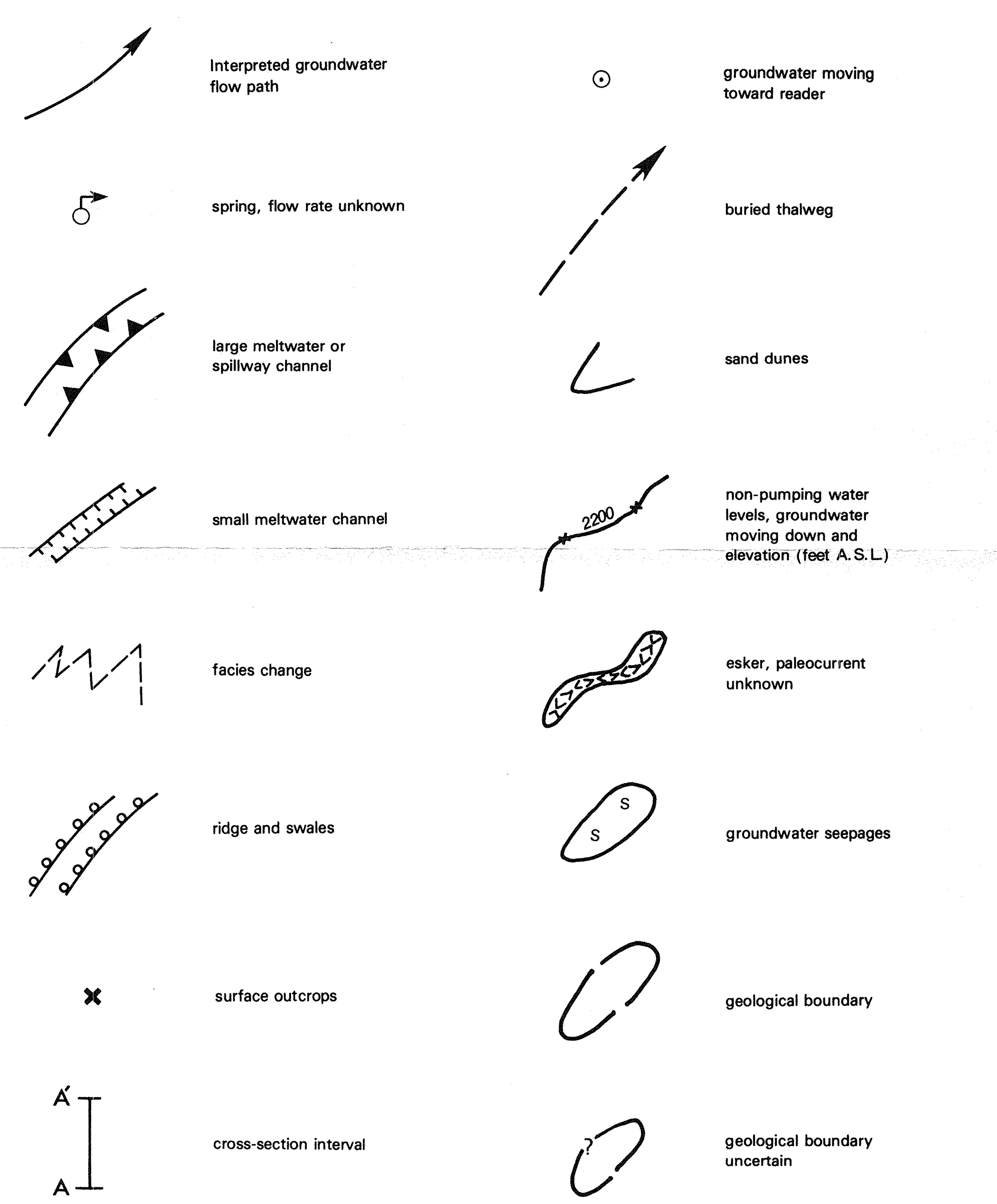
Colors (estimate only)

gy -	gray
yel -	yellow
org -	orange
rd -	red
wh -	white
br -	brown
blk -	black
bl -	blue
gn -	green
pi -	pink

GENERAL SYMBOLS



GEOLOGICAL SYMBOLS



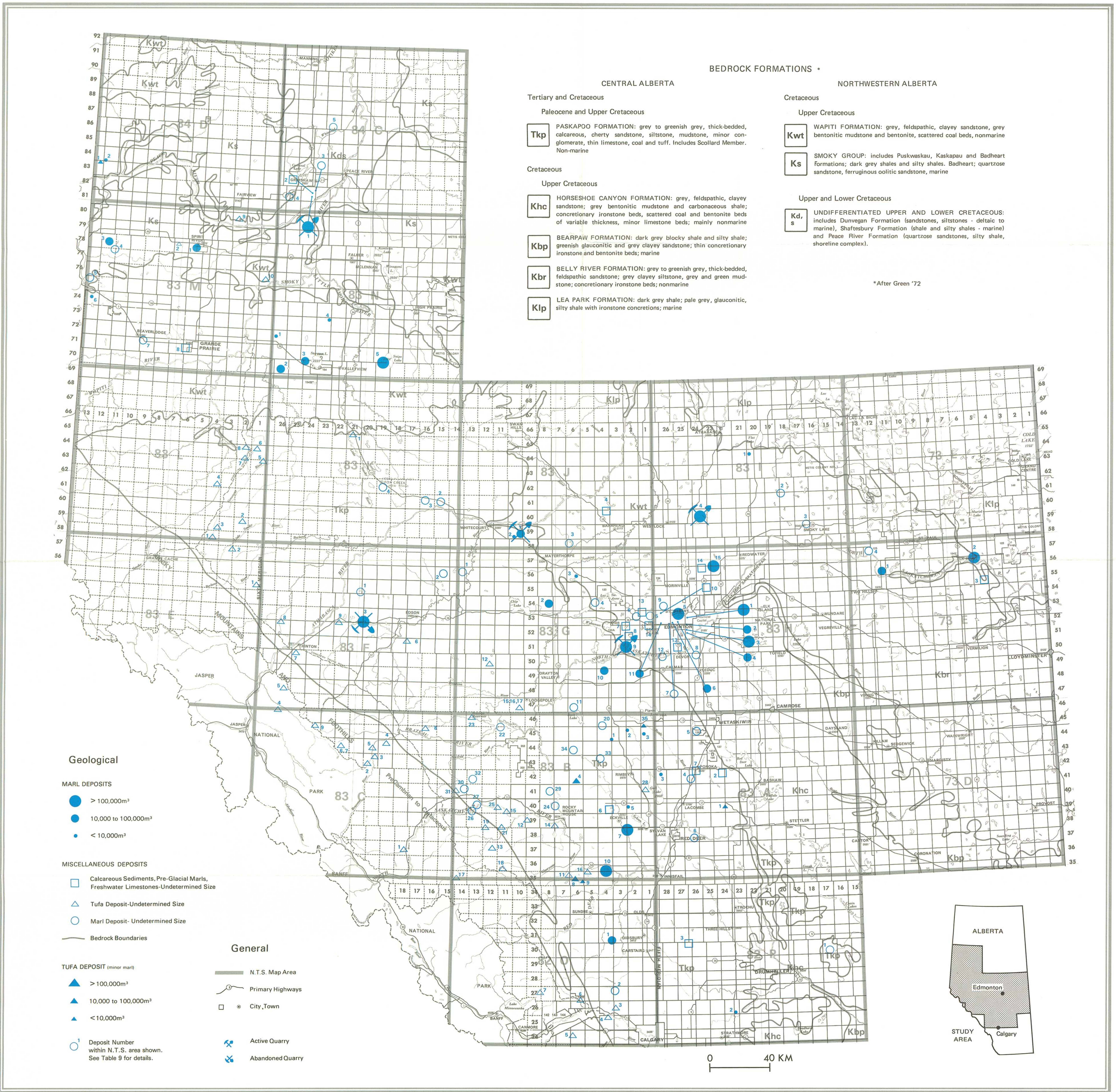


FIGURE 38. Marl and tufa deposits in northwestern, north-central, west-central, and south-central Alberta.

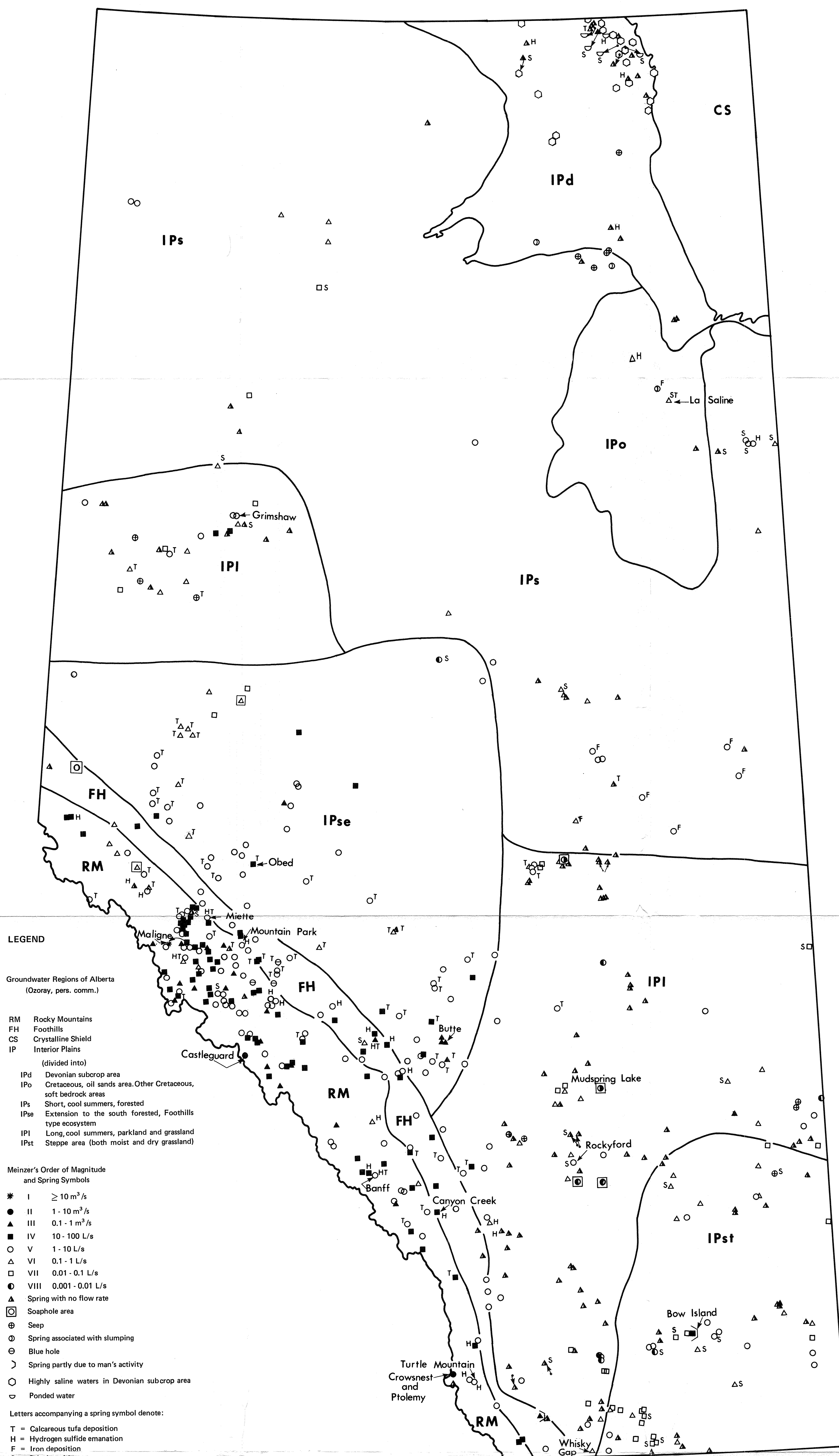


FIGURE 1 - DISTRIBUTION AND SIZE OF ALBERTA SPRINGS

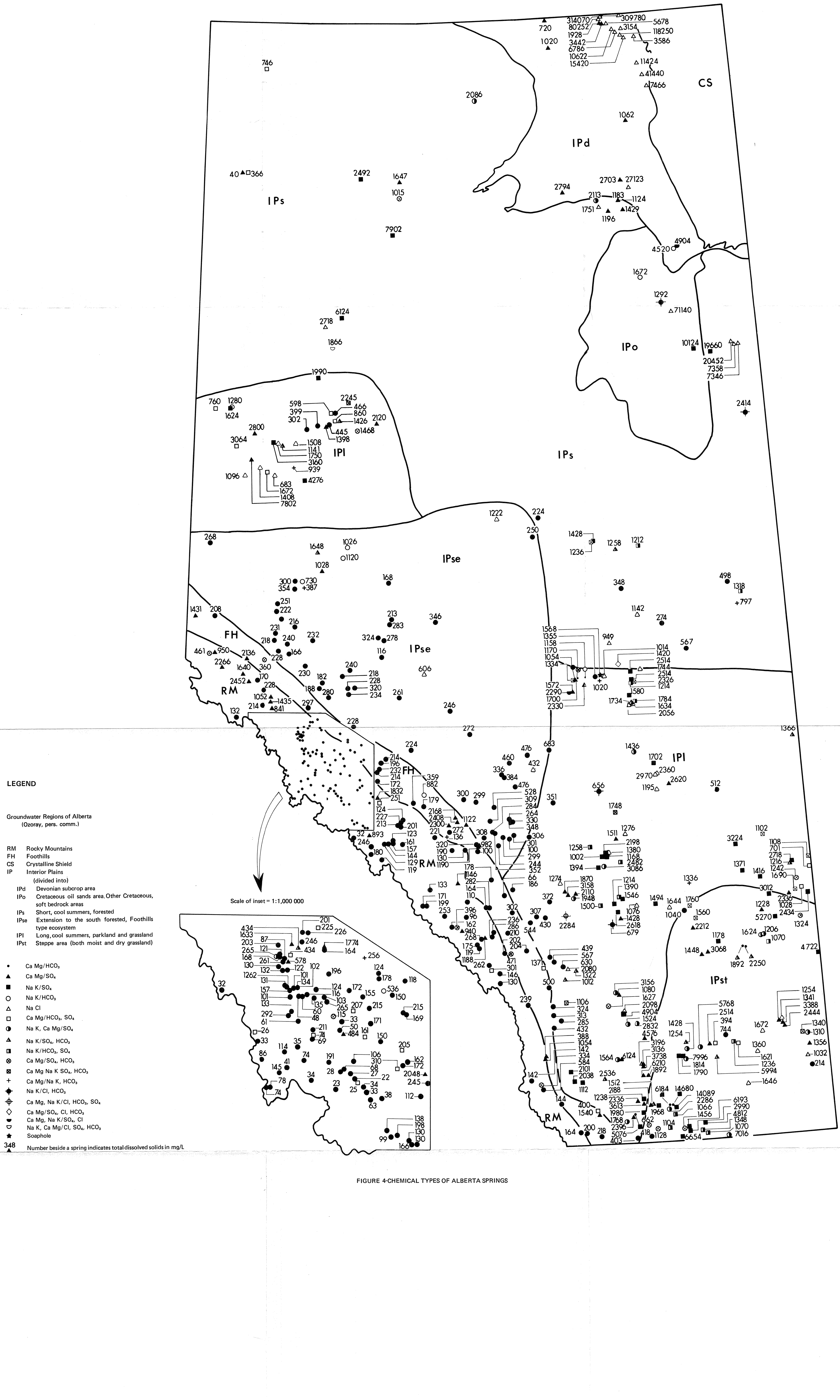


FIGURE 4-CHEMICAL TYPES OF ALBERTA SPRINGS

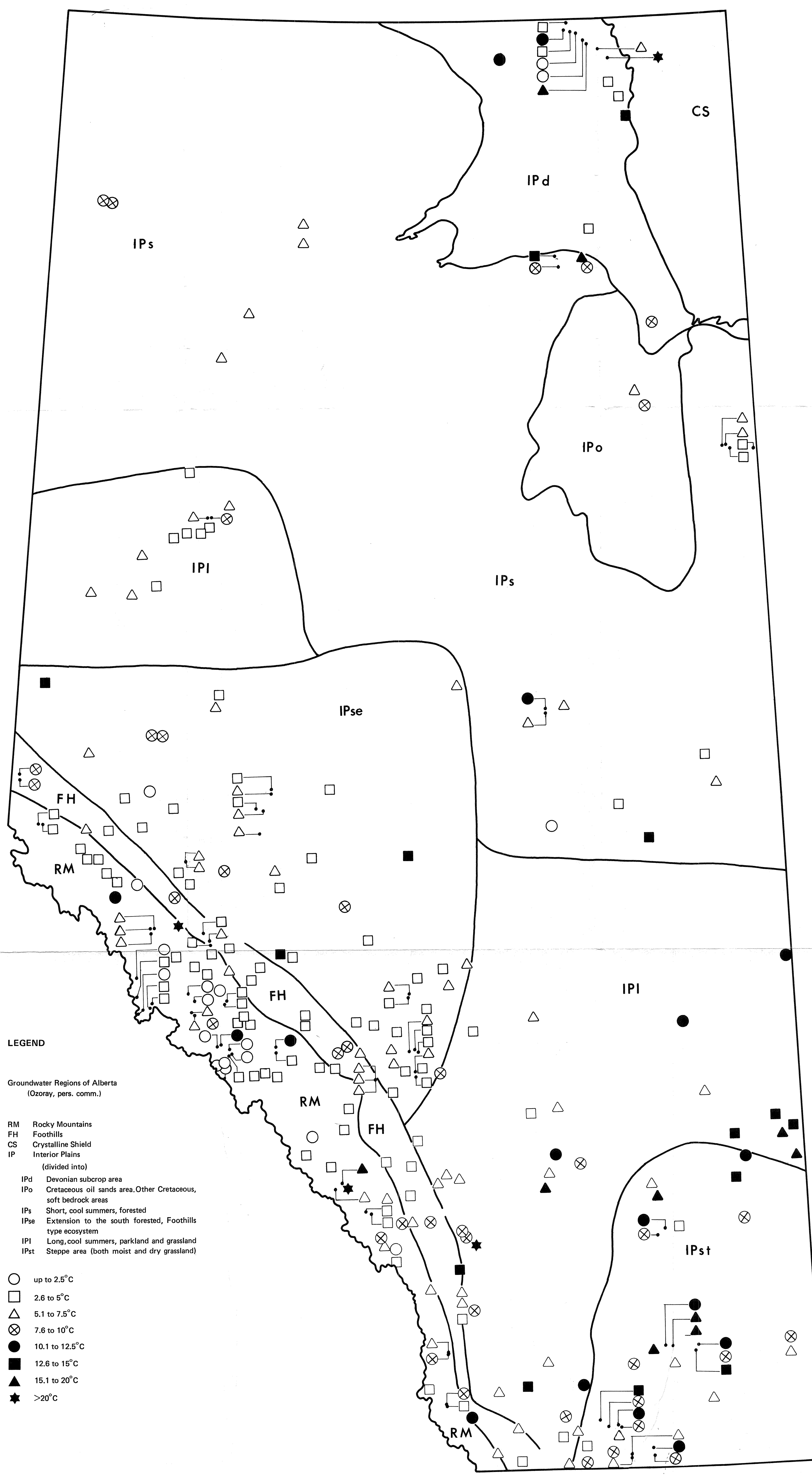


FIGURE 3 - TEMPERATURE OF ALBERTA SPRINGS

LEGEND FOR BEDROCK GEOLOGY OF ABLERTA
(after Green, 1970)

NORTHERN ALBERTA

Devonian

Upper Devonian

- Dg Grosmont Formation
- Dmk Mikkwa Formation
- Di Ireton Formation
- Dw Waterways Formation
- Dc Caribou Member, Slave Point Formation

Middle Devonian

- Dn Nyarling Formation
- Dm Middle Devonian

Proterozoic

- Ᵽa Athabasca Formation

Archean

- Am Metasedimentary Rocks
- Agg Granite Gneiss
- Ag Granite
- Ap Porphyroblastic Granite

NORTHERN ALBERTA

Devonian

- Dh Hay River Formation
- Dc Caribou Member, Slave Point Formation

Middle Devonian

- Dfv Fort Vermilion Member, Slave Point Formation
- Dmg Muskeg Formation
- Dk Keg River Formation
- Dch Chinchaga Formation
- Df Fitzgerald Formation

Archean

- A Undivided Plutonic Rocks

ROCKY MOUNTAINS AND FOOTHILLS

Tertiary and Cretaceous

Paleocene and Upper Cretaceous

- Tkb Brazeau Formation

Cretaceous

- Ka Alberta Group

Mesozoic

- Mz Lower Cretaceous, Jurassic and Triassic

Paleozoic

- Pzu Upper Paleozoic
- Pzl Lower Paleozoic

Proterozoic

- Ᵽm Miette Group
- Ᵽp Purcell Group

NORTHWESTERN ALBERTA

Tertiary and Cretaceous

Paleocene and Upper Cretaceous

- Tkp

Cretaceous

Upper Cretaceous

- Kwt Wapiti Formation
- Kpw Puskwaskau Formation
- Kph Bad Heart Formation
- Kk Kaskapau Formation
- Kd Dunvegan Formation

Upper and Lower Cretaceous

- Ksh Shaftesbury Formation

Lower Cretaceous

- Kp Peace River Formation
- Kl Loon River Formation

NORTH CENTRAL ALBERTA

Cretaceous

Upper Cretaceous

- Kwt Wapiti Formation
- Ks Smoky Group
- Kd Dunvegan Formation

Upper and Lower Cretaceous

- Ksh Shaftesbury Formation

Lower Cretaceous

- Kl Loon River Formation
- Kb Basal Cretaceous

NORTHEASTERN ALBERTA

Cretaceous

Upper and Lower Cretaceous

- Klb La Biche Formation

Lower Cretaceous

- Kpl Pelican Formation
- Kj Jolifou Formation
- Kac Alice Creek Tongue, Grand Rapids Formation
- Kg Grand Rapids Formation
- Kc Clearwater Formation
- Km McMurray Formation

SOUTHWESTERN ALBERTA

Tertiary

Paleocene

- Tp Porcupine Hills Formation

Tertiary and Cretaceous

Paleocene and Upper Cretaceous

- Tkw Willow Creek Formation

Cretaceous

Upper Cretaceous

- Kwb Whitemud and Battle Formations
- Ksm St. Mary River Formation
- Kbo Blood Reserve Formation
- Ko Oldman Formation
- Kfm Foremost Formation
- Kpa Pakowki Formation
- Kmr Milk River Formation
- Ka Alberta Group

SOUTHEASTERN ALBERTA

Tertiary

Oligocene

- Tc Cypress Hill Formation

Eocene

- Ti Intrusives

Tertiary and Cretaceous

Paleocene and Upper Cretaceous

- Tkr Ravenscrag Formation

Cretaceous

Upper Cretaceous

- Kwb Whitemud and Battle Formations
- Ke Eastend Formation
- Kbp Bearpaw Formation
- Ko Oldman Formation
- Kfm Foremost Formation
- Kpa Pakowki Formation
- Kmr Milk River Formation
- Ka Alberta Group

CENTRAL AND EASTERN ALBERTA

Tertiary

Pliocene?

- Th Hand Hills Formation

Tertiary and Cretaceous

Paleocene and Upper Cretaceous

- Tkp Paskapoo Formation

Cretaceous

Upper Cretaceous

- Kwb Whitemud and Battle Formations
- Khc Horseshoe Canyon Formation
- Kbp BearPaw Formation
- Kbr Belly River Formation
- Klp Lea Park Formation

FIGURE 30