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STRATIGRAPHY AND DISTRIBUTION OF QUATERNARY SEDIMENTS IN CENTRAL EDMONTON

BY

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ABSTRACT

In central Edmonton exposures of Quaternary sediments are limited to temporary excavations, however, there is an abundance of information from drilling. Over 600 borehole logs and samples from four boreholes were studied to determine the stratigraphy and distribution of the sedimentary units. The average geotechnical properties of these units are derived from a large data base from engineering consulting companies, the University of Alberta and the City of Edmonton. By correlating the borehole units with interpreted sections located outside of the study area but within the city, the genesis of the sediments in central Edmonton was inferred. The geotechnical implications of the sediments are summarised.

The Quaternary stratigraphy above Upper Cretaceous sediment, considered bedrock, in central Edmonton, consists of preglacial fluvial sand, glaciofluvial sand and gravel, a diamicton complex of two subglacial tills (deposited predominantly by melt out) and flow diamicton, glaciofluvial sand and silt, glaciolacustrine silt and clay, and postglacial fluvial sand. Diamictons comprising the diamicton complex possibly represent two periods of ice occupation, but were probably deposited during one major glaciation in the Late Wisconsinan. Preglacial sand infills the Stony Valley which is incised into bedrock. Thin glaciofluvial deposits discontinuously overlie preglacial sand or bedrock. The diamicton complex is

continuous over most of the study area. Clay till is discontinuous at the base of the complex, most of the complex is composed of clay-silt-sand till, and sand flow diamicton occurs discontinuously in the upper complex. The diamicton complex is generally thinner over bedrock highs and thicker over the Stony Valley, and is locally thicker and contains more sand lenses where the flow diamicton component is greater. Outwash sand is continuous within a meltwater channel which was cut through the diamicton complex and incises bedrock. Interbedded outwash, flow diamicton and glaciolacustrine sediments form a broad ridge over the meltwater channel. Fine grained glaciolacustrine deposits blanket the area, vary the least in thickness and are thickest over the Stony Valley. Postglacial fluvial sand occurs in small deposits adjacent to the modern North Saskatchewan River valley. The diamicton complex contains a variety of sediment types and geotechnical conditions. Large buried meltwater channels infilled with sorted sediment can provide unexpected changes in conditions unless detected and mapped.

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PURPOSE AND SETTING

A. Introduction

The paucity of sediment exposures and the variability of the glacial sediments in central Edmonton makes prediction of subsurface conditions difficult for construction and tunnelling projects. Abundant borehole information, however, can be used to characterise the sediments and determine their distribution, and by correlating with known regional stratigraphy, the genesis of the units can be determined. Geotechnical properties of the sediments in Edmonton are used to characterise the units and to correlate between field and borehole stratigraphy. The maps of unit distribution will be useful for site investigation purposes, and the interpretation of depositional environments of the sediments and their geotechnical implications will be useful in engineering practice.

B. Objectives

The objectives of this research are to:

1) Determine the regional stratigraphy by describing and interpreting field sections.

2) Characterise the borehole sediment units in central Edmonton.

3) Construct isopach and contour maps of borehole sediment units to determine their distribution, and cross sections

to examine their variability.

4) Correlate the borehole units with interpreted field units and thus determine the genesis of the sediments in central Edmonton.

5) Discuss the geotechnical implications of the Quaternary sediments in central Edmonton.

C. Regional Setting

1. LOCATION

The City of Edmonton is situated on the Interior Plains of Canada, at an elevation of about 660 m a.s.l. with regional drainage toward the northeast (Fig. 1.1). The city lies on a gently undulating plain bisected from southwest to northeast by the North Saskatchewan River. The average depth of the river valley is approximately 50 m. Two sections were investigated, the Big Bend section in the North Saskatchewan River valley, and the Clover Bar section in a gravel pit (Fig. 1.1). The borehole study area is in the centre of the city, north and south of the river valley (Fig. 1.1).

2. CLIMATE

The climate is continental, varying between dry and moist subhumid. Warm summers and cold winters are usual with moderate precipitation in all seasons. Mean monthly temperatures reach a low of -15 degrees celsius in January and a high of 17 degrees celsius in July, with a mean annual temperature of 3 degrees celsius (Atmospheric and Environment Service 1983). Predominant wind direction

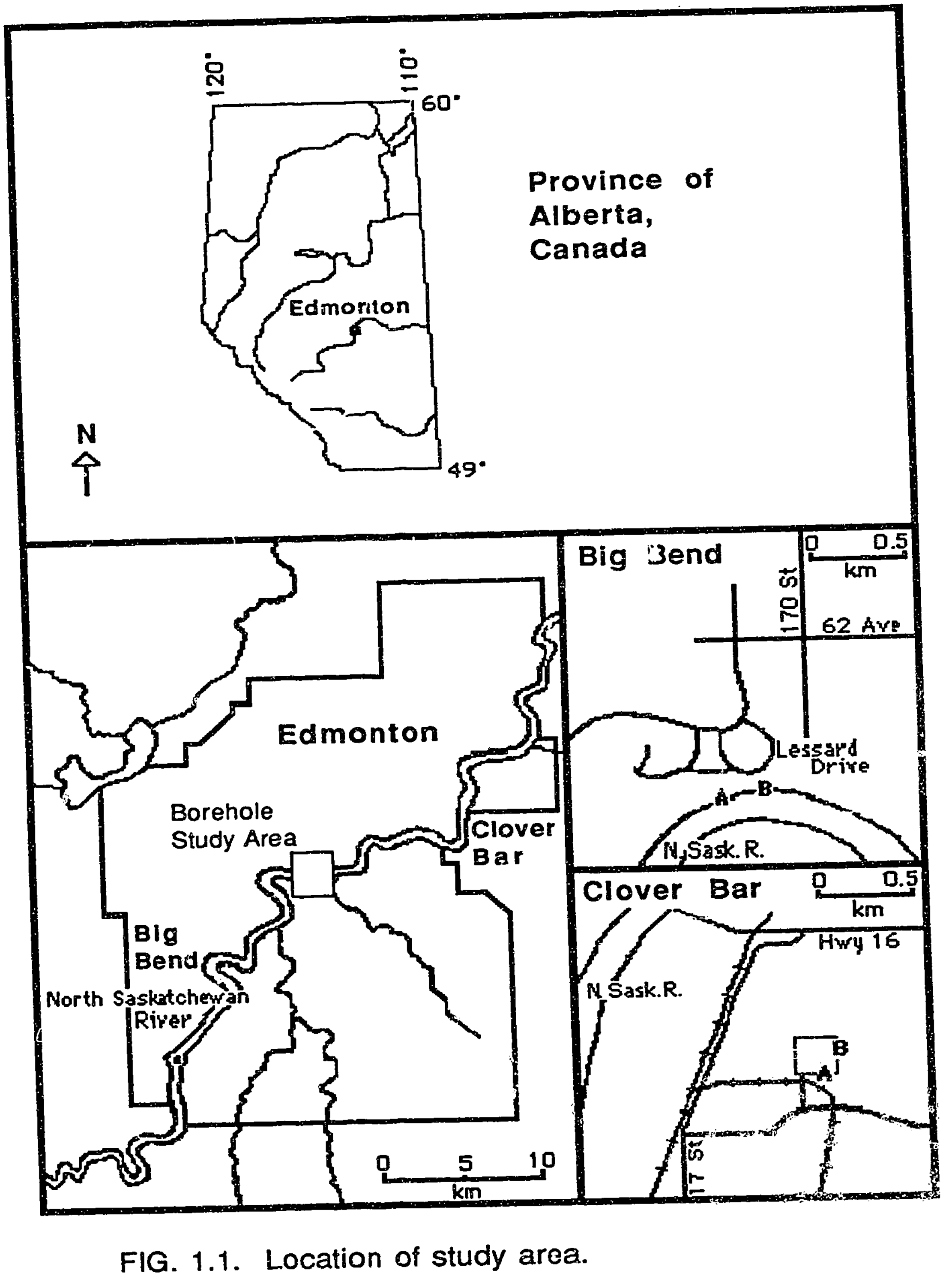


FIG. 1.1. Location of study area.

alternates between south and northwest. Yearly mean windspeed is 14 km/hr, with peak annual gusts averaging 117 km/hr. Relative humidity is generally low because of the drying effect of the Rocky Mountains on Pacific Air Masses, averaging 68% annually. Total precipitation averages 46.6 cm per year with approximately 70% falling as rain and the rest as snow.

3. SOILS AND VEGETATION

Edmonton lies within the Aspen Parkland Vegetation zone, a mixture of grassland and Aspen stands of the forest-grassland transition (Pettapiece 1969). Within the Edmonton 1:250,000 mapsheet (83H) there is a gradation from open parkland in the west to continuous forest in the east (Bowser 1962).

The parkland is dominated by Chernozemic soils, formed under grassland vegetation of a rough fescue association (Bowser 1962). Aspen poplar (*Populus tremuloides*) is the principal tree type. Areas of Solonetzic, and gradations between Chernozemic and Solonetzic soils, are found on the east side of the mapsheet. Gleysolic soils occur in poorly drained sites. Gleysolic and Solonetzic soil types are found locally within the City limits, mainly in the southeast quarter (Lindsay and Scheelar 1972).

The continuous forest is dominated by Luvisolic (Grey Wooded) soils. Aspen poplar (*P. tremuloides*) and balsam poplar (*P. balsamifera*) are the principal tree types.

The vegetation transition zone is reflected in the soils, which may exhibit characteristics of both

Chernozemic and Luvisolic types of formation in varying degrees of dominance (Pettapiece 1969).

4. BEDROCK GEOLOGY

The weakly-consolidated, sedimentary Upper Cretaceous Edmonton Group is considered bedrock and underlies Quaternary sediments throughout the city. They dip approximately 4 m/km to the southwest.

Irish (1970) divided the Edmonton Group into three formations. The lowermost Horseshoe Canyon Formation outcrops in Edmonton, and consists of interlensed bentonite and argillaceous sandstone, bentonitic shales and coal seams.

5. BEDROCK TOPOGRAPHY

An integrated, dendritic preglacial drainage pattern is evident in the Upper Cretaceous bedrock topography as mapped by Carlson (1967) and Kathol and MacPherson (1975), (Fig. 1.2). The west to east trending Beverly Valley crosses the northern part of the city. It is up to 8 km wide, with gently sloping valley wall gradients averaging 2%. The depth of the valley is generally about 60 m, with an average gradient of about 0.5 m/km to the east. The Stony Valley is a major tributary to the Beverly Valley within the city and is relatively narrow, but also has a gentle gradient. Other smaller tributary valleys enter the Beverly Valley from the north and south and are relatively short with gradients of up to 5 m/km. Bedrock highs with little surface relief are found between preglacial valleys.

Younger bedrock valleys can be distinguished from

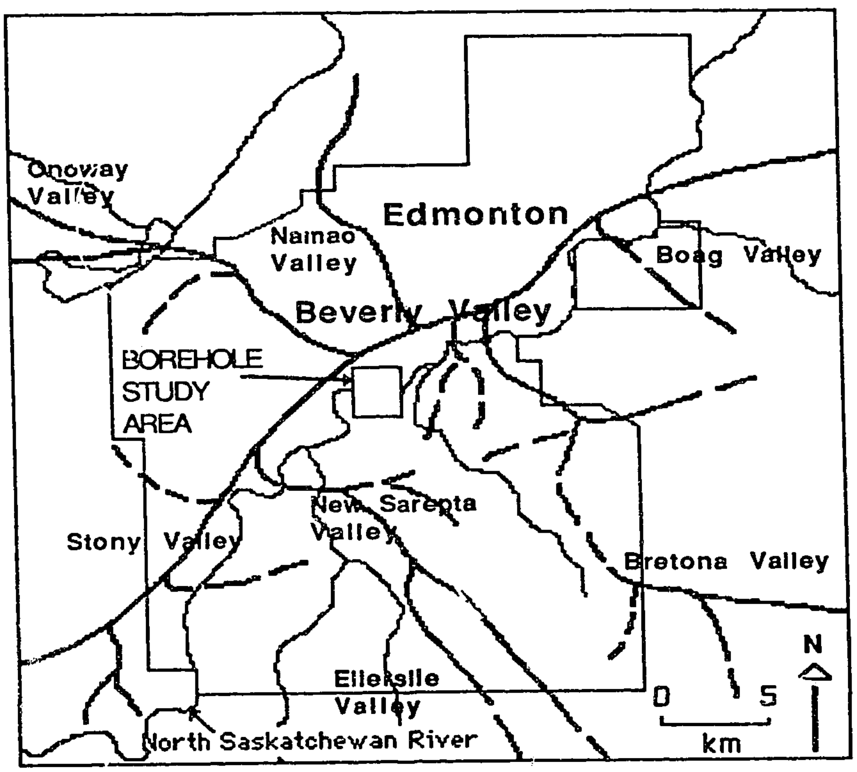


FIG. 1.2. Thalwegs of preglacial valleys in Edmonton. Modified after Kathol and MacPherson (1975).

preglacial bedrock valleys in the area by their narrow and steep-sided cross sections. Examples are the Gwynne Outlet to the south of the city formed during rapid drainage of Glacial Lake Edmonton, and the Sturgeon River Valley east of St. Albert which is related to glacial drainage systems (Bayrock and Hughes 1962).

The postglacial North Saskatchewan River Valley locally cuts across bedrock highs, or follows preglacial valleys. Within the city, it is narrow and steep-sided compared to major preglacial valleys. To the east of the city, however, it rejoins its preglacial course along the Beverly Valley.

6. PHYSIOGRAPHY AND SURFICIAL GEOLOGY

Edmonton is situated on a flat to undulating glaciolacustrine plain (Fig. 1.3). Uplands coincide with preglacial topographic highs, and lowlands occur over major preglacial valleys. In the southeast of the city, lake sediments border till plains and hummocky moraine. South of the city, scablands occur where glacial lake drainage caused erosion. West of the city are large areas of pitted delta, early postglacial North Saskatchewan River alluvium, and extensive aeolian dune fields. Glacial lake sediments extend north of the city.

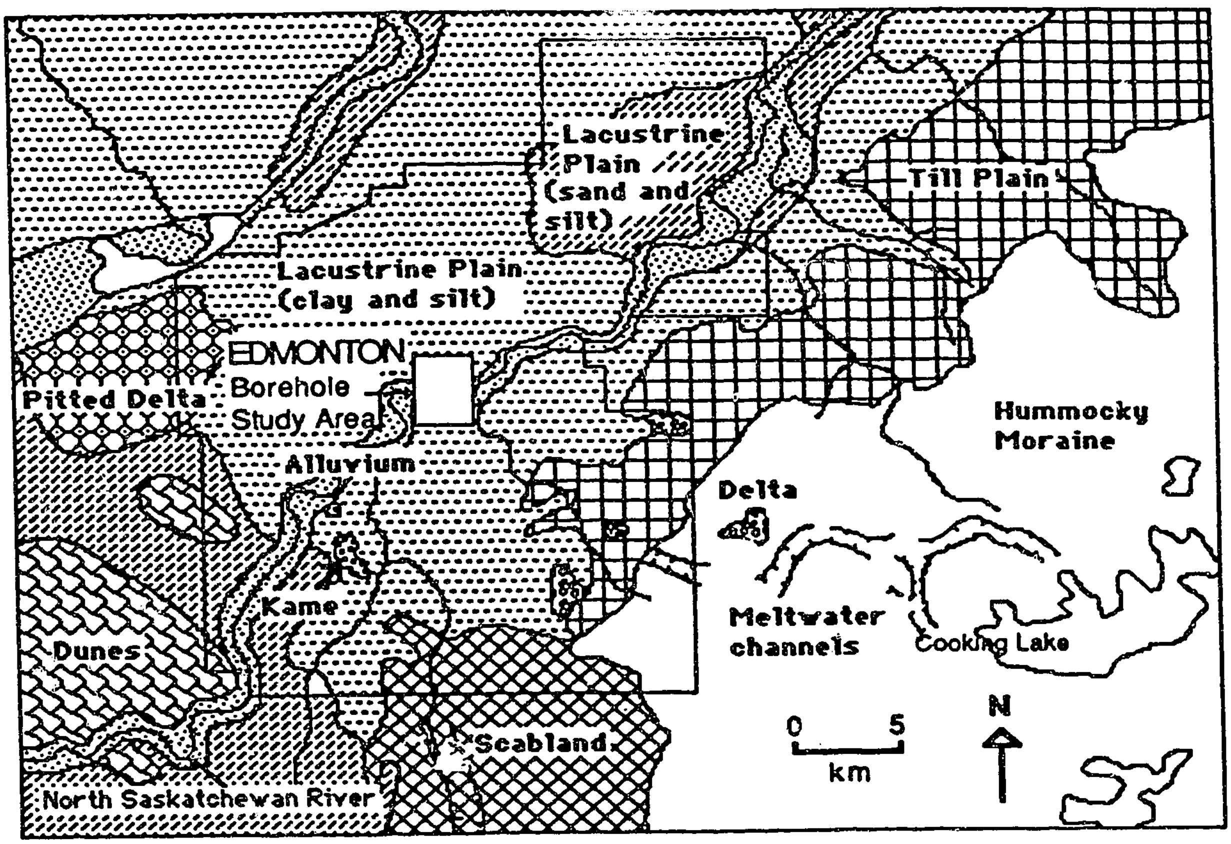


FIG. 1.3. Surficial deposits in Edmonton. Modified after Bayrock and Hughes (1962).

CHAPTER II

PREVIOUS WORK

A. Stratigraphy

Early study of the Quaternary geology of the Interior Plains involved regional study of the dominantly quartzitic gravels unconformably overlying Upper Cretaceous bedrock and underlying glacial sediments, the distribution of glacial deposits and the lacustrine deposits at the surface (Dawson 1875, McConnell 1885, 1890, Tyrell 1887, Coleman 1909).

McConnell (1885) termed any thick post-Miocene gravel and sand units over bedrock "South Saskatchewan Gravels", regardless of their mineralogy and lithology. He considered them to be alluvial, and suggested that those containing rock clasts derived from the Canadian Shield to the east could postdate those containing only quartzite. Tyrell (1887) did not observe Precambrian Shield clasts in the gravels and therefore considered them to be entirely preglacial, with uppermost units dominantly sand with some silt beds. The gravels probably were derived from Late Tertiary conglomerates on uplands and were redistributed to lower elevations. Dawson and McConnell (1895) renamed the strata "Saskatchewan Gravels". Dawson (1895,1898) considered the entire gravel complex as proglacial or glaciofluvial, either originating from mountain or continental glaciation, and grading up into "boulder clays".

In the Edmonton area, Taylor (1934) noted that the distribution of the quartz-rich gravels over bedrock did not strictly follow the course of the modern North Saskatchewan River. He considered the Saskatchewan Gravels to contain no Shield clasts and therefore to predate glacial activity in the area. Crossbedded sands 4.6 to 27 m thick overlying the Saskatchewan Gravels contained Shield pebbles. Rutherford (1937) formalized the definition of the unit, which he called the "Saskatchewan Gravels and Sands", to exclude gravels of Shield provenance. These deposits were recognized to be present along ancient, well-defined drainage courses. A preglacial, integrated drainage system in Edmonton was delineated using drilling information by Carlson (1967) and Kathol and MacPherson (1975).

Gravenor and Bayrock (1961) considered the Saskatchewan Gravels and Sands to be preglacial Quaternary deposits, excluding erosional remnants of Tertiary fluvial systems. Bayrock and Hughes (1962) separated the preglacial Quaternary gravel and sand into three topographic levels. The oldest and topographically highest gravel units cap hills, and vertebrate fossil evidence indicates an Early Pleistocene age. Intermediate deposits are found in buried terrace deposits. The youngest deposits are valley fill in preglacial bedrock valleys and, according to fossil evidence, could be Mid- to Late Pleistocene in age. All three groups have similar clast lithology dominated by quartz, chert and some arkose pebbles, and no igneous or metamorphic clasts. Westgate (1969) observed that the preglacial sediments are chiefly composed of quartzose sandstone and black chert clasts, with some arkosic sandstone, jasper and local bedrock material such as coal, petrified wood, and clay ironstone. Glacial sediments contain abundant igneous and metamorphic pebbles, and fresh pink feldspar and higher heavy mineral contents in the sand fraction.

Stalker (1968) established the Saskatchewan Gravels and Sands as a preglacial, Quaternary fluvial complex containing clasts of Cordilleran origin, deposited in a regional, integrated drainage system. The deposit lacks material from the Canadian Shield and lies directly over bedrock, at a lower altitude than any Tertiary units in the area. On the basis of the fossil assemblage within some Saskatchewan sediments conforming to Stalker's criteria, Reimchen (1968) considered the age of the youngest preglacial sediments as Late Pleistocene. A Bison sp. vertebra indicates that the deposit is not older than the Wisconsinan. Grün et al. (1987) electron spin resonance-dated a mammoth tooth found within preglacial fluvial sediments near Edmonton, and the age is between 90 and 128 ka, corresponding to oxygen isotope stage 5e or the Sangamon Interglacial. Radiocarbon-dated wood from sand and gravel beneath a single diamicton near Smoky Lake, about 100 km northeast of Edmonton, yielded dates of 21,600 ± 900 years BP (Gravenor and Ellwood 1956), and >31,000 years BP (S.92, McCallum and Dyck 1960). To the northwest of Edmonton, Westgate et al. (1971, 1972), and Liverman et al. (1989), have radiocarbon-dated wood in preglacial sediments as Mid-Wisconsinan, indicating that west-central Alberta was not glaciated until the Late Wisconsinan. The youngest date on wood, is 31,530 ± 1440 (AECV-416C, UA-2399) (Liverman et al. 1989).

Westgate and Bayrock (1964) identified gravel involutions, ice-wedge pseudomorphs and vertically oriented stones within the Saskatchewan Gravels and Sands. These relict periglacial features developed during a period of cold, moist climate prior to glaciation. A former active layer about 1.5 m thick is rust-stained by ferric and manganese oxides, possibly from freezing of solutions in pore spaces. Berg (1969) identified sand wedge pseudomorphs and ventifacts within Saskatchewan Gravels and Sands which developed during a period of cold and dry periglacial conditions. Wood in the sediments was Carbon 14-dated in excess of 35,000 years B.P. (Geochron Laboratories GX-0106 and GX-0210), (Berg 1969).

Whitaker and Christiansen (1972) classified all fluvial sediment both preglacial and glacial in age, overlying bedrock and underlying glacigenic diamicton, as the Empress Group.

Duff (1951) used the Big Bend section in Edmonton (Fig. 1.1) as the type locality for a regional stratigraphy of three tills interbedded with stratified sediments, all overlying Saskatchewan fluvial deposits. He did not observe Shield lithologies in the sands below the lowermost glacigenic diamicton. The lowermost diamicton, termed the "Grey Till", is described as thin, not stony, tough, fissile and with a patchy distribution, mostly in depressional areas. Discontinuous, brown to buff, crossbedded sands occur over the Grey Till. The overlying diamicton, termed the "Brown Till", is described as massive, stony and columnar jointed when dry and weathered. Crude horizontal stratification occurs in the lower part of the Brown Till in places. Overlying the Brown Till are clays, silts, sands and gravels, overlain by what Duff (1951) called "Silt Till" or "Waterlain Till". Postglacial fluvial and ponded sediments top the three-advance sequence. Hughes (1958) concluded that the Silt Till of Duff (1951) is a lacustrine deposit, possibly a proglacial lake deposit and supraglacial in origin. Sand between the Grey and Brown Tills was termed the "Tofield Sand", after the type exposure, now inaccessible, southwest of Edmonton, where the sand was 13 m thick (Warren 1954). Shell fragments and peat within the sand were not dated.

Bayrock and Hughes (1962) did not recognise two separate tills in Edmonton, but observed that a single diamicton unit is brown near the surface and grades down into unoxidised grey to dark grey at depths of 3 to 9 m. The glacigenic diamicton is similar to others elsewhere in central Alberta (Pawluk and Bayrock 1969), with an average matrix composition of approximately 42% sand, 32% silt, and 26% clay, and a high content of montmorillonite in the clay fraction reflecting local bedrock composition. Bayrock and

Hughes (1962) suggested that the last ice advanced approximately 20,000 years B.P., and deglaciation occurred approximately 10,000 years B.P.

In a borehole study on the east side of downtown Edmonton, Bayrock and Berg (1966) observed thick preglacial sediments, consisting mainly of sorted, rounded, quartz sand, with gravel beds at the base of the unit averaging 1 m in thickness and containing bedrock fragments in large proportions. The grey and brown diamictons of Warren (1954) are considered as one diamicton unit deposited during a single glaciation, affected by post-depositional oxidation. Stratified sand and gravel lenses, usually less than 0.3 m thick, are common within the diamicton. The overlying glaciolacustrine sediments are commonly brown, but grey in some locations at depths of greater than 6 m. In a borehole study of the Garneau and University areas, Roed (1966a, 1966b) found predominantly glacial sand and gravel beneath glacigenic diamicton. Sorted sediments between two diamictons considered to possibly represent two tills are discontinuous.

Westgate (1969) correlated a Lower Till and Upper Till with the grey and brown tills of Duff (1951) and Warren (1954). The Lower Till is described as greyish brown, up to 6 m thick, with few stones and some inclusions of stratified sediments. It is highly fractured, with preferred stone orientations of northwest-southeast. The Upper Till is described as yellowish brown, dense, massive and up to 8 m thick. It is generally coarser grained than the Lower Till and has a pronounced columnar structure, with preferred stone orientations and sole markings oriented northeast-southwest (Westgate 1968). Pockets of sand occur along the contact between the two diamictons. Lithology of both tills is similar. Westgate (1969) considered the Lower Till to be no younger than Early Wisconsinan, and the Upper Till to be Late Wisconsinan in age.

Ramsden (1970) concluded that it was not possible to use pebble fabrics alone to assign a stratigraphic position within an upper and lower diamicton framework and Ramsden and Westgate (1971) suggested that pebble fabric of a Lower Till may have been substantially altered by an overriding glacier of a second advance. In the Clover Bar area, the Lower Till was observed to contain three distinct zones; a basal sheared layer several cm thick, a middle dense and massive zone and an upper fractured zone with many shear surfaces. Mechanisms for alteration were suggested to include displacement along relatively incompetent clay layers and shearing of the diamicton itself along minute shear planes.

Two diamicton units in the Fort Assiniboine area northeast of Edmonton, had a detrital log fragment between them radiocarbon-dated at 52,200 $\pm$ 1760 years B.P. (GSC 1019-2), although contamination of the sample by lignite particles could invalidate the date (St-Onge 1972b).

In boreholes located on a one mile grid around the city, Kathol and McPherson (1975) observed different-coloured diamictons, but were unable to confirm the presence of two separate tills, or the continuity of interdiamicton sand and gravel lenses. Westgate et al. (1976) could not definitely identify a two-till stratigraphy at the Big Bend section. A slight colour change is the only noticeable difference between a lower darker diamicton that grades up indistinctly into a lighter one. Two diamictons were distinguished by a sharp colour transition in the Clover Bar area, but pebble lithology, pebble fabric and carbonate content do not distinguish them. The lower unit is slightly more clayey. In the Cooking Lake Moraine east of Edmonton several diamicton units were described, with a lower darker diamicton squeezed up and sheared in places. Some orientations of vertical joints in Edmonton diamicton were observed to be largely correlative to bedrock joint orientations of 042/132 and 005/95 degrees described by Babcock (1974) in the Cretaceous bedrock of central Alberta.

Emerson (1977) described two diamicton units in the Cooking Lake Moraine, with a very thin pink diamicton between them in places. The lower diamicton is darker and has smaller, more compact jointing than the well developed columnar jointing of the upper diamicton. Texture, pebble lithology, mineralogy and carbonate contents were not useful in differentiating the units, but the lower diamicton has a higher montmorillonite content. Jennings (1983) obtained a date of 26,000 $\pm$ 1100 years B.P. (S-2160) on organics in a silt and clay unit between two diamicton packages from a borehole in the Cooking Lake Moraine, however, the diamictons are not well described.

Andriashek (1988) named three diamicton units in the Edmonton region. From oldest to youngest, these are the Lamont, Chipman and Cooking Lake Tills. They are characterised on the basis of stratigraphic position, discontinuous interdiamicton sorted sediments, texture, mineralogy, resistivity and carbonate content. Considerable overlap in values between the diamictons make regional correlations indefinite. The most extensive diamicton unit is the uppermost Cooking Lake Till, commonly found directly overlying bedrock. Stratigraphically lower diamictons are usually within preglacial bedrock valleys.

Other workers have used a sedimentologic approach to interpret the genesis of Edmonton diamictons. Rains (1969a) suggested that a lower grey diamicton and upper brown diamicton may represent basal till overlain by supraglacial till, sediments deposited by fluctuations of one major ice advance or deposits from two separate advances. Shaw (1982) interpreted the dominant process of deposition of glacigenic diamictons west of Edmonton to be passive melt out. At Huggett, he recognised two stratigraphically distinct diamicton units which required two glacial advances for their deposition, with periglacial conditions sustained between advances. At Villeneuve he found direct evidence for one glacial advance, with the possibility of erosion of an earlier-deposited diamicton by fluvial processes. In further work at Villeneuve, Shaw

(1987) described several diamicton and sand and gravel sediment units. A complex assemblage of lodgement till, basal melt-out till, subglacial flow deposits and subglacial fluvial channel deposits, were laid down during the final glacial advance in the area. The highly variable stratigraphy is attributed to the glacier having been alternately in contact with and separated from its bed. A small component of lodgement activity was recognised at the planar, erosional, lower contact of the diamicton with underlying fluvial sediments, where sole casts parallel to regional ice movement direction were present. The main diamicton types are interpreted as basal melt-out and subglacial mass movement deposits, grading laterally into one another. Sandy and much softer, less-consolidated flow diamictons were deposited with running water present. Although the evidence for two possible advances is not discounted, Shaw (1987) suggested that two suites of glacigenic sediments should not be expected at all sites.

Catto (1984) examined sediments at the Convention Centre site in downtown Edmonton. Sandstone bedrock grades upward into an intensely weathered regolith up to 0.9 m thick and enriched in quartz. Preglacial sands and gravels over bedrock have thrust structures oriented to the east. Preglacial sediments are light yellowish brown, with some iron oxide and manganese oxide staining. Flame-shaped diamicton lenses occur within discontinuous glaciofluvial deposits deposited in a subglacial channel sequence, beneath a diamicton complex. A single layer of pebbles occurs along the contact of the glaciofluvial deposits with overlying melt-out till. The diamicton complex is composed of four diamicton types of melt-out and supraglacial origin, produced during a single glacial advance. The complex reaches a maximum total thickness of 12 m, and is overlain by glaciolacustrine sediments. Basal melt-out till containing 15% pebbles and cobbles grades up into englacially transported till containing 5% or less, and uppermost flow diamicton is very silty, with approximately 2% gravel. Clasts in the complex grade up from subrounded to subangular. Pebble fabric in the basal melt-out till is parallel to ice motion and moderately strong, and parallel but weaker in the englacial till. Flow diamictons have lobate or fan-shaped pebble fabric distributions. Diamicton facies grade into one another laterally, and colour changes occur laterally and vertically. Randomly located sand lenses with sharp contacts and no preferred current direction are present throughout all of the diamicton facies. Catto (1984) postulated that the absence of deposits from an earlier advance may be due to non-deposition or erosion. Regular joint patterns are consistent with downslope creep of the sediments over bedrock into the modern river valley, in the manner suggested by Babcock (1977). Irregular jointing is attributed to dessication.

Regional mapping of glacially oriented landforms by Gravenor and Bayrock (1955), Gravenor and Meneley (1956), and Westgate (1968) showed that the last Laurentide ice flow in the Edmonton area was to the southwest. Moran et al. (1980) described ice-marginal glacial-thrust and up-glacier streamlined landforms in the Edmonton area.

Features of ice stagnation are prevalent in central Alberta (Gravenor and Kupsch 1959; Stalker 1959), and according to Bayrock and Hughes (1962), the retreat of the last Laurentide ice was dominated by rapid ice melting in the Edmonton area. Bayrock (1972) mapped the surficial geology of the Edmonton mapsheet (83H), recognising minor kame and esker deposits as well as postglacial loess.

Hughes (1958) named a proglacial lake which formed when the last Laurentide glacier dammed regional drainage to the northeast, "Lake Edmonton". The Gwynne Outlet, recognised earlier by Bretz (1943) to be a meltwater channel, was identified as the major drainage channel for the lake (Hughes 1958). Taylor (1960) generally discussed the distribution and drainage of the lake. St-Onge (1972a) outlined the sequence of glacial lake development in north-central Alberta, and subdivided Hughes' (1958) single lake basin of Lake Edmonton into several phases which included Glacial Lake Leduc and Glacial Lake St. Albert, the former draining south through Gwynne Outlet and the latter to the northeast through Bruderheim. St-Onge (1972a) estimated the lake outlet elevations which showed that the lakes had maximum depths of 25 to 75 m.

Lake Edmonton deposits were classified by Bayrock and Hughes (1962) as normal (bedded fine sands, silts and clays), modified (normal deposits subsequently disturbed or overlain by other materials), and pitted delta (fine to medium grained sand and silt). Lake deposits range in thickness from 0.3 to 30 m and typical sequences have bedded fine sands and silts with some diamicton inclusions grading up into a thick set of silt and clay rhythmites becoming more clayey toward the top, overlain by sand and silt of fluvial origin. Surface sand and silt were deposited by the early postglacial North Saskatchewan River during later stages of the lake. Gabert (1968) observed three units in the glaciolacustrine sequence at a locality southwest of Edmonton: 1) a lowermost unit of 1.5 m thick, well bedded poorly sorted sands that were penecontemporaneously folded; 2) a middle unit of 1.2 m thick diamicton; and 3) an upper unit of 4.5 m thick rhythmically bedded fine grained sediment. Shaw (1975) described thick bodies of sand between underlying diamicton units and overlying lacustrine rhythmites. The sands are normally graded and were deposited in glaciolacustrine delta environments. Westgate et al. (1976) classified the lake sediments as a three part sequence. The lowermost sediments are commonly poorly sorted and contain diamictons and penecontemporaneous deformational structures, horizontally bedded silts and clays form the middle of the sequence and massive clays form the uppermost part. Rhythmically bedded sands, silts, and clays are locally separated from underlying diamictons and deformed stratified sediments by an undulatory unconformity.

May (1977) termed the diamictons deposited subaqueously "lacustrotill", deposited primarily by flow mechanisms, and "waterlaid till", deposited beneath the snout of a glacier grounded in a lake, during minor ice readvances into a lake basin or beneath a glacier floating in a lake. He suggested that clasts of aggregated silt and clay ("clay balls") within the lacustrotill could be diagnostic of glaciolacustrine deposition.

Kulig (1985) performed a detailed sedimentologic analysis of glaciolacustrine sediments in exposures at Wetaskiwin, southeast of Edmonton, where the glacier ice margin was grounded in a proglacial lake. He recognised several diamicton types deposited by subaqueous gravity flows, diamictons formed during ablation of calved brash ice and diamictons originating from the disturbance of subaqueous debris banks. The sections had yellow-brown upper parts and grey to black lower parts. The colour boundary followed beds or lenses of silt, clay or sand, or where bedding features were absent, the boundary passed through several diamicton types. Sedimentary features were destroyed in the upper zone, which was overconsolidated and had well developed columnar jointing. This was concluded to be a weathering effect, likely due to postglacial changes in groundwater level such as a possible sharp groundwater drawdown during a dry warm climate in Mid-Holocene time.

The highest terrace levels of the modern North Saskatchewan River at 45 and 30 m above the river are features formed by a northeasterly flowing stream emptying into one of the last glacial lakes (Westgate et al. 1976). Regional correlation suggests formation about 12,000 to 11,000 years B.P. (St-Onge 1972b, Westgate et al. 1976). Emerson (1983) dated molluscs in supraglacial lacustrine sediments in the Cooking Lake Moraine at 10,900-9050 years BP, indicating that melting ice was still present at that time. Rains (1969b, 1988) and Westgate et al. (1969) studied and dated terraces. Since about 5,000 years B.P. the North Saskatchewan River has cut through the lowermost terrace and into bedrock (Westgate et al. 1976).

B. Engineering Geology

Carlson (1967) outlined the preglacial integrated drainage system but did not differentiate between preglacial and glacial sorted sediments infilling the valleys, stating only that preglacial fluvial deposits were generally more permeable, most likely to occur infilling preglacial valleys, and could be significant aquifers. Kathol and MacPherson (1975) discussed the urban geology of the Edmonton area, further defined the preglacial drainage system and delineated deposits of preglacial sand and gravel. In the North Saskatchewan Valley on the University of Alberta campus, Thomson (1970) noted the presence of two buried bedrock valleys, a large one intersecting the campus area in the northwest and a small one crossing the east side of the campus approximately from north to south.

Westgate (1969) observed local deformation from glacial overriding along the surface of Edmonton Group bedrock. Babcock et al. (1977) examined glacial shear thrusts in preglacial fluvial gravels in central Alberta. Fenton (1987) postulated a possible mechanism of formation of ice-thrust sediments and bedrock in the Wabamun area west of Edmonton. Stacking of units by thrusting caused repetition of sequences in geologic sections. Tsui et al. (1988) examined fabrics in ice-thrust bedrock west of Edmonton.

Bayrock and Berg (1966) and Kathol and MacPherson (1975), generalised geotechnical characteristics for various Quaternary deposits. Thomson (1969) and Fredlund and Dahlman (1971) summarised some geotechnical properties of the surface glaciolacustrine clays.

Dejong and Harris (1970) and Dejong and Morgenstern (1973) showed that two multistory buildings in downtown Edmonton founded in overconsolidated glacigenic diamicton displayed a rapid settlement response to loading during the construction process. Dejong and Harris (1970) found that predictions of settlements using laboratory test results from soil samples taken at the sites are unrealistically high when compared with measured settlements, due to an undetermined amount of disturbance by sampling.

Based on Ramsden and Westgate's (1971) reorientation of fabric hypothesis, May and Thomson (1978) suggested that overriding of a lower diamicton by another advance reworked the upper approximately 1 m, resulting in a zone of intense fracturing that could be a zone of weakness and greater fracture permeability. Another possible zone of weakness would be a thin sheared zone observed by Ramsden and Westgate (1971) at the base of the lower diamicton. Other influences on strength could be the upper columnar joint pattern and the lower rectangular joint pattern, as well as lenses of water-bearing sand within diamicton. The water table is usually located at least 25 to 30 m below the ground surface. The diamicton complex is unsaturated and test holes throughout central Edmonton do not show a static water table. Perched water tables occur above the complex or in sand lenses within the complex, and water in some lenses is under a substantial hydrostatic head. Most of the glacigenic diamictons are overconsolidated, and May and Thomson (1978) suggested that dessication could have contributed to overconsolidation and produced columnar jointing. Preconsolidation of a preexisting diamicton may have occurred during ice loading induced by a second glacial advance. Thomson et al. (1982) identified "soft zones" in the diamicton which have low blow counts, observed in the lower part of the diamicton complex, which they suggested could be a diamicton deposited by debris flow.

Rutter and Thomson (1982) discussed implications of the Quaternary geology in Edmonton on engineering endeavors, suggesting that the variability in properties of the glacigenic diamicton could be attributed to different environments of deposition. Matheson (1970) observed rectangular blocks fall from the roof of a tunnel being excavated entirely in glacial diamicton, and concluded that sand lenses contributed to the failure.

Slope failures in Edmonton are commonly seated in bedrock or glaciolacustrine clay (Matheson and Thomson 1973, Babcock et al. 1976, Thomson and Yacyshyn 1977, Thomson and Morgenstern 1979).

CHAPTER III
METHODOLOGY

A. Fieldwork

Fieldwork was conducted during 1987. Investigation of sections along the North Saskatchewan River Valley and in excavations within the city resulted in the use of two exposures to determine the stratigraphy and characterise the sediments. The sections are at Big Bend and Clover Bar (Fig. 1.1).

Sediments were described according to colour (Munsell colour), texture, lithology, water content (Appendix A), compactness or hardness (Appendix A), sedimentary structures, thickness, lateral extent, contacts with underlying and overlying sediment and jointing. All units were bulk sampled for laboratory analysis.

Sampling of diamicton pebble fabrics consisted of measuring the orientation of the long axes of pebbles which were at least 1 cm in length with a:b ratios of at least 2:1, within an area of approximately 0.25 m^2 on the face of diamicton units. Each sample consisted of trend and plunge measurements on at least 25 clasts, a number which has been shown to give statistically valid orientation results (Mark 1973). The pebble fabrics were plotted using the Apple MacIntosh contour program STEREO, Version 3.4, 1987, and rose diagram program ROSY, Version 1.3, 1988, both written by D.B. McEachran.

Pebble samples for lithological determination were taken from diamicton units. Pebble, cobble and boulder percentage estimates were made for diamictons.

Pocket penetrometer tests were done on cohesive sediments. The spring in the pocket penetrometer is calibrated in terms of unconfined compressive strength, which can be approximately correlated to twice the undrained shear strength of a cohesive sediment, although pebbles and fissures can affect the results (Holtz and Kovacs 1981).

B. Borehole Data Collection

During 1986 and 1987, 612 drill logs from holes drilled between 1955 and 1986 in central Edmonton were collected from the University of Alberta Planning Department, the City of Edmonton and three engineering consulting companies (Thurber Consultants Ltd., Hardy-BBT Consultants Ltd. and EBA Consultants Ltd.). Logs were included in the study if their location was clearly indicated, no other more detailed logs were located within a distance of about 10 m, they penetrated at least one sediment unit and sediment descriptions were adequate. Split spoon samples were obtained from four holes (Nos. 580, 582, 601, 602; see Appendix B) drilled by Thurber Consultants Ltd. in 1985 for the Light Rapid Transit Line on the south side of the North Saskatchewan River.

Boreholes are located in the study area by Northing and Easting coordinates, according to a cadastral UTM grid for the City of Edmonton (Fig. 5.1, in pocket).

Sediments are named according to dominant sediment texture. Some logs were adjusted to standardise sediment type, with minor shifts or additions of boundaries between types, or renaming of types where appropriate to eliminate genetic bias, as in changing "till" to "diamicton".

Data on unit colour (qualitative), texture, Unified Soil Classification (Appendix A), sedimentary structure, water content, water table level, penetration resistance (standard and pocket penetrometer), Atterberg limits, wet and dry density, unconfined compressive strength, and consolidation parameters, were compiled from logs.

The Standard Penetration Test (SPT) consists of a standard "split spoon" tube sampler being driven by a 63.5 kg hammer falling 0.76 m (ASTM 1980). The number of blows required to drive the sampler down for a vertical distance of 0.3 m is called the standard penetration resistance or blow count (N). A semi-disturbed sample is removed from the tube. Boulders can cause erroneous results and sampling problems (Holtz and Kovacs 1981). The effective stress increases the N value with depth so that it is higher than the value reflected solely by the relative density of the sediment. A depth correction can be made using the general relation:

$$N_1 = C_N \times N$$

where N_1 is blow counts corrected for overburden pressure, and C_N is the correction factor. Various values for C_N in normally consolidated sand are given by Skempton (1986). The depth correction is more important for evaluating relative density of sands rather than for cohesive sediments (S. Thomson, Civil Engineering, University of Alberta, personal communication 1988). The application of the test to estimate relative density has been widespread, mainly for cohesionless soils. A standard relative density scale has very dense sand having blow counts of greater than 50, and hard clay having blow counts of greater than 30 (Terzaghi and Peck 1948). Skempton (1986) has shown that the blow counts generally increase with increasing particle size, aging, and overconsolidation of a given sand deposit.

The pocket penetrometer and unconfined compressive strength tests are generally unsuited for analysis of diamicton because the presence of pebbles can influence the results of tests on small samples, causing a wide range of values (Kemmis et al. 1979), however, a relative hardness scale for pocket penetrometer values was used (Appendix A).

C. Laboratory Work

Laboratory tests were done on a total of 105 field and borehole samples. Textural analysis was done using the hydrometer and sieve methods (ASTM 1964). Only the less-than-2 mm size fraction of the diamictons was subjected to textural analysis. Sediments were classified in the Unified Soil Classification System (Appendix A).

Pebble lithology determinations were made for glacigenic diamicton units from field sections. Sand mineralogy determinations using binocular microscopic analysis were done on sorted sediments stratigraphically below the diamicton complex to determine their preglacial or glacial origin.

Atterberg limit determinations were made on fine grained sediments and the fine grained matrix of diamictons for grain sizes less than 0.425 mm (ASTM 1980). Atterberg limits are percentage water contents at which the behaviour of a sediment changes (Casagrande 1948). The liquid limit is the water content at which the sediment has such a small shear strength that it flows to close a groove of standard width when jarred in a specific manner. The plastic limit is the water content at which the sediment begins to crumble when rolled into threads of specified size. The difference between the liquid and plastic limits, or plasticity index, is the range of water contents in which a sediment behaves as a plastic.

Atterberg limit tests were done on air-dried, thoroughly remoulded samples. Liquid limits were determined using the standard liquid limit device and grooving tool (ASTM 1980), distilled water to moisten samples, a balance with sensitivity of 0.01 g and a drying oven and dishes. For each sample, three or more trials on well-mixed sediment at varying moisture contents gave a plot of blow count and moisture content. The moisture content at 25 blows was read from the plot as the liquid limit. Plastic limits were determined using a glass plate on which thoroughly mixed moist sediment was rolled with the palm of the hand until a 3 mm diameter thread showed signs of crumbling (ASTM 1930). Moisture contents from two or more trials were averaged as the plastic limit.

D. Genetic Interpretation of the Sediments

1. INTRODUCTION

Genetic interpretation is based upon sedimentology, sedimentary association, sediment properties and stratigraphic position. Engineering properties aid in correlation and can reflect the depositional and post-depositional history of the sediment. Genetic interpretation from borehole information is limited because complete sections of undisturbed sediment cannot be observed and borehole descriptions are not standardised. Specific interpretation of borehole units relies on correlation with interpreted field sections.

Terrain resulting from temperate continental glaciation can be generalised into subglacial and supraglacial landsystems (Eyles 1983). The ice sheet bed is a shear surface on the glacier substrate of bedrock, preglacial sediments, interglacial sediments or previous glacial sediments. The wet-based ice slides over the bed and the tops of sediment sequences deposited subglacially are often streamlined or truncated. This streamlined bed can be veneered by other glacial sediments deposited subglacially or supraglacially during glacier retreat. Edmonton is located within sedimentary lowlands of subglacial till and supraglacial moraine complexes (Eyles et al. 1983).

Subglacial deposits of temperate glaciers are formed from debris concentrated in a thin zone of basal ice of a glacier, commonly less than 1 m in thickness (Dreimanis 1976, Lawson 1981). Basal debris is brought to the ice surface when the ice is under compression, at the thinning margin of a decelerating ice sheet where the ice can be frozen to the substrate, at large scale topographic obstructions or at the junction of two ice lobes (Sugden and John 1976). It is thereby exposed on the glacier surface and melted out or resedimented.

2. CLASSIFICATION OF GLACIGENIC SEDIMENTS

Glacigenic sediments are divided into five major categories (cf. Kulig 1985):

a) tills, formed and deposited directly by glaciers.

b) debris flow assemblages, commonly associated with stagnant ablating ice.

c) subaquatic sediment assemblages, formed in glaciolacustrine or glaciomarine settings by various processes such as sediment flow, calving ice, undermelting of floating ice, and turbidity currents.

d) glaciofluvial deposits, associated with proglacial outwash plains and stagnant ice deposits.

e) glaciotectonic deposits.

The various glacial sediments commonly occur in typical lithofacies associations as described by Eyles and Miall (1984), and Edwards (1986).

"Diamicton" is a non-genetic term for "any non-sorted or poorly sorted sediment that contains a wide range of particle sizes" (Dreimanis 1982a). "Glacigenic diamicton" refers to any diamicton made up of sediment originating from debris carried by a glacier and deposited in a glacial environment, including glacial debris deposited by subaerial or subaquatic mass movements off glacial ice. Glacial origin is indicated mainly by the presence of glacially abraded (striated and faceted) clasts, clasts of erratic (distal) lithology and bimodal or multimodal particle size distributions (Dreimanis and Schlüchter 1985). Glacigenic diamictons are a distinctive type of geological and engineering group of sediments which have a wide range of behavioral patterns and high degree of variability (McGown and Derbyshire 1977). "Till" refers to relatively undisturbed diamicton transported and deposited directly by, and in contact with, glacial ice, with little or no sorting by water, and which has not undergone disaggregation or resedimentation subsequent to deposition (Dreimanis 1976, Lawson 1981). "Proglacial", "ice-marginal", "supraglacial", "englacial" and "subglacial", are generalised genetic terms which refer to the location of glacigenic diamicton formation (Shaw 1982).

The principal types of glacigenic diamicton are lodgement till, melt-out till and flow diamicton. Lodgement and melt-out tills have been called primary deposits (Lawson 1981) or ortho-tills (Dreimanis 1984). Flow diamicton has been called flow till (Boulton 1968), secondary till (Dreimanis 1976), debris flow (Lawson 1979), or allo-till (Dreimanis and Lundqvist 1984). Other types of glacigenic diamicton include glaciotectonic or deformation diamicton formed at the ice-substrate interface by shear stress exerted by the moving ice, waterlain diamicton melted out of floating ice and lee-side diamicton formed in cavities in the lee of hummocks beneath the ice (Dreimanis and Lundqvist 1984).

Lodgement till is "till deposited from the base of a dynamically active glacier by pressure melting and/or other mechanical processes" (Dreimanis 1982a). Melt-out till is "till formed by the melting of debris-rich ice that is neither sliding nor deforming internally in the zone of formation" (Shaw 1982). Melt-out till can be formed through melting of the ice supraglacially or subglacially (Boulton 1970, Lawson 1981). Flow diamicton is "(diamicton) deposited by any mass movement of debris on or from glacial ice" (Dreimanis 1982a). Flow diamicton can be formed supraglacially, proglacially or subglacially, and is a secondary deposit because it does not retain the properties originally imparted to the debris by glacial transport (Lawson 1981).

Distinguishing diamictons deposited in different glacial environments can be difficult or impossible (Sugden and John 1976). Those deposited directly by glacier ice commonly grade into resedimented deposits and often they are indistinguishable even in the modern environment (Dreimanis 1982a, Lawson 1979). A single criterion is insufficient to distinguish various types, and various criteria must be met to support probable genesis (Table

3.1), (Lawson 1979, Boulton and Deynoux 1981, Haldorsen and Shaw 1982, Edwards 1986, Dreimanis 1987).

Properties of glacigenic diamictons that have been used to differentiate them are colour (White 1960, Westgate 1969, Mickelson et al. 1977), texture (Shepps 1953, Elson 1961, Chryssafopoulous 1963, MacDonald and Sauer 1970, Dreimanis 1976, Mickelson et al. 1977, Kemmis et al. 1979), water content (Peck and Reed 1960, Fookes et al. 1975, Mickelson et al. 1977, Kemmis et al. 1979), Atterberg limits (Smith 1968, MacDonald and Sauer 1970, Fookes et al. 1975, Boulton and Paul 1976, Mickelson et al. 1977, Kemmis et al. 1979, Nowak 1983), lithology and mineralogy (Goldthwait 1971, McGown 1971, Mickelson et al. 1977), void ratio and bulk density (Easterbrook 1964, Boulton and Paul 1976, Mickelson et al. 1977, Kemmis et al. 1979), standard penetration test values (Olmsted 1969, Mickelson et al. 1977), overconsolidation ratio (Kazi and Knill 1973, Mickelson et al. 1977, Kemmis et al. 1979), angle of internal friction (Mickelson et al. 1977), cohesion (Mickelson et al. 1977), activity (Mickelson et al. 1977), unconfined compressive strength (Mickelson et al. 1977), carbonate content (MacDonald and Sauer 1970), geophysical response (MacDonald and Sauer 1970), jointing (Westgate 1969, Christiansen 1970, Kazi and Knill 1973), and fabric (Westgate 1969, Lindsay 1970, Boulton 1971, Lawson 1981).

3. ENGINEERING PROPERTIES OF GLACIGENIC DIAMICTONS

Glacial deposits which are direct products of

TABLE 3.1. Criteria by which some terrestrial glacigenic diamictons may be identified. Modified after Boulton and Deynoux (1981) and Dreimanis (1987).

Criterion	Lodgement Till	Melt-out Till	Flow Diamicton
Surface expression, distribution, geometry	Ground moraines and other subglacial landforms. Can be traced for at least several kms in sheets tongues, and wedges, and can thicken from source to marginal areas, thinning again at the fringe.	Ice marginal landforms of ice stagnation. Kms in breadth. Tabular.	Ice marginal landforms or thin surface layer on other glacial landforms. Localised, lenticular.
Nature of sequence in which sediment lies	Over bedrock, or pre-advance sediments or glaciotectonites unless they have been eroded. At base of retreat sequence. Locally underlain by meltwater channel deposits. Overlain by any glacigenic sediments. Associated with proglacial outwash.	Directly over lodgement till or glacier substrate. May occur as lenses in lodgement till or interbedded with englacial meltwater deposits. Locally underlain by subglacial meltwater deposits or flow diamicton. Overlain by ice stagnation sediments. Grades up into flow diamicton or supraglacial outwash.	Uppermost in glacigenic diamicton sequence. Locally associated with subglacial tills in cavities beneath the ice or proglacial deposits overridden by ice. May be interbedded with glaciofluvial or glaciolacustrine sediments. Often above glacial outwash showing collapse structures.
Nature of basal contacts	Sharp, usually erosional, planar and can have clast pavements along contact. Can appear gradational if substrate is incorporated. May be folded overthrusted or sheared. Can be interbedded or deformed with deformation till which strikes transverse to ice movement. Substrate may be grooved or sheared. Bedrock is usually abraded. Erosion marks under contact and alignment of clasts immediately above contact have same orientation.	Sharp, usually erosional. Subglacial meltwater may modify contact by eroding erosion marks or producing convex-up channel fills and other scour features. Erosion marks under contact and alignment of clasts immediately above contact have same orientation.	Sharp, concordant or erosional. May be interbedded with other sediments. Seldom planar over long distances. May fill topographic irregularities in underlying sediment. Erosional sole marks are parallel to local flow direction. Load structures occur when subaqueous flow is deposited over soft sediments.
Thickness	Usually one to	Thin, usually less	Extremely variable,

	several metres up to tens of metres. Laterally constant, subdues underlying topography.	than two metres. Laterally variable regionally.	usually several cms to several metres. Can be stacked to great thicknesses. Laterally discontinuous.
Sedimentary Structure, Bedding, Banding	Almost entirely massive. Clast pavements or ellipsoidal boulder clusters, elongated in ice-flow direction. Thin, tabular or triangular lenses of stratified sediment can be deposited by subglacial meltwater, having gradational, sharp, or deformed contacts. Subglacial channel fills have truncated upper surfaces. Smudges or silt and sand laminae mark subglacial shear planes parallel or gently inclined to regional bedding and frequently isoclinally folded.	Largely massive with some lenses of sorted sediment or silt and sand laminae. Can have near-horizontal stratification preserved of texturally or lithologically distinct debris bands in the ice. Sorted sediments are draped over large clasts. Rafts of substrate sediment and soft sediment inclusions are preserved.	Massive, graded, or stratified. Flow structures, folds, shear banding, lobes, roll-up structures, stretched-out clay, silt and sand intraclasts, dewatering diapirs and flame structures, silt stringers, and load structures. Primary structures, lenses of sorted sediment and boulder lags can form on the surface of flows. Normal or reverse grading of large clasts. Subaqueous flows can be interbedded with silt which can contain dropstones or pods of diamicton.
Folding Faulting	Can be highly attenuated.	Rare internal folds.	Folding common, highly attenuated and warped bedding due to melting of underlying ice. Gravity faulting or deformation.
Grain Size Distribution	Wide variety, may be relatively homogeneous over large areas or show systematic variation. Poorly sorted, bi- or polymodal diamicton with substantial fine sand and silt fraction. Consistent except for boulder clusters and the lower 0.5 to 1 metre which reflects local substrate.	Polymodal diamicton with substantial fine sand and silt fraction. May be winnowed or show variations inherited from debris bands in the ice.	Polymodal diamicton, extremely variable due to winnowing or enrichment of fines. Sorting or grading may develop.
Lithology	Materials of local derivation near basal contact. Regionally consistent or systematic variation in	Materials of distant derivation more common than in lodgement till of same glacial	Similar to lithology of source material mixed with incorporated substrate clasts. Incorporated

	mineralogy and geo- chemistry of matrix.	package. Local at base,distant at top.	soft sediment clasts common.
Clast Shapes	Subangular to sub- rounded, glacially smoothed, polished, striated, faceted or fractured. Impact marks. Boulders with smooth upper surfaces and rough bases. Bullet-shaped boulders with smooth noses pointing up- glacier,and rough down-glacier.	Subangular to sub- rounded, glacially smoothed, striated, faceted and rounded.	Similar to source material. May contain rounded water-reworked clasts with no striations.
Fabric	Strong, parallel to glacial movement, up- glacier imbrication. May have transverse component due to flute and fold form- ation.Large scale aerial consistency.	Strong, parallel and transverse to glacial movement. Reduced dip of clasts and weakened orientation due to meltout process. Tendency to large scale aerial consistency.	Parallel and trans- verse to flow direction. Large variation in orient- ation locally from random to strongly oriented. Often un- related to direction of glacial movement. Up-flow imbrication.
Consolidation	Overconsolidated. Variable due to subglacial deform- ation.	Usually normally consolidated. Less consolidated when supraglacially formed.	Wide variation. Usually normally consolidated, locally overcons- olidated due to dess- ication when clayey.
Density	High bulk density, penetration resist- ance, and seismic velocity. Can have upper remoulded hor- izon of lower density.	Bulk density and penetration resist- ance lower than lodgement till.	Variable. Usually lower than lodgement, slightly higher than melt-out till. Sub- aqueous lower than melt-out till. Can be loose.
Porosity	Low permeability.	Variably permeable.	Variable. Very permeable when cont- inuous sand and gravel horizons present.
Jointing	Fissile, foliated. Subhorizontal and widely spaced reflect unloading and shear- ing (slickensides). Vertical related to stress applied by moving glacier. Closely spaced and parallel to surface caused by freezing.	Rare.	Vertical and polygonal plan reflect dessication. Closely spaced and parallel to surface caused by freezing.

comminution typically have bimodal grain size distributions consisting of large composite grains and rock fragments formed mainly by frost action and crushing, and matrix single grains and minerals formed mainly by attrition and chemical weathering, with the division occurring in the sand size fraction (Dreimanis and Vagners 1971). Glacigenic diamictons with a coarse fraction less than approximately 40% are "matrix dominant" (McGown and Derbyshire 1977). Larger coarse fractions are uncommon and are mainly found in subglacial zones of deformation (Sladen and Wrigley 1985). Dreimanis and Vagners (1971) showed that newly eroded debris was clast dominated, but as transport and comminution proceeded, a second mode in the silt range developed and eventually became dominant, with the extent of comminution dependent upon the mineralogy of the source rocks. Diamictons subjected to enrichment or washing out of fines have different grain size distributions than tills formed by direct comminution (Fig. 3.1). Subglacial diamicton matrix texture is generally finer than supraglacial diamicton matrix texture (Elson 1961, Drake 1971, Dreimanis 1976), and an increase in clast angularity is common from subglacial to englacial, to supraglacial diamictons (Drake 1971, Boulton 1978). Generally supraglacial till has wider ranges in geotechnical properties than subglacial till, often due to interbedding with stratified deposits.

Subglacial till tends to have distinctive ranges in physical and geotechnical properties that are uniform over

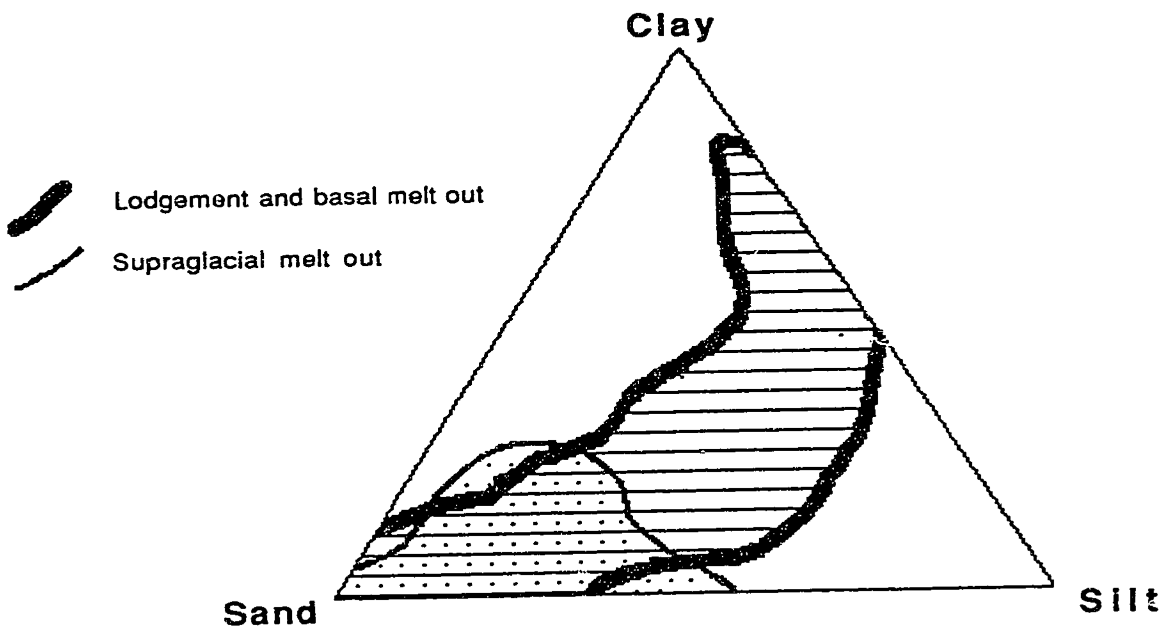


FIG. 3.1a. Matrix grain size distribution envelopes for glacigenic diamictons, compiled from a variety of sources. Modified after Sladen and Wrigley (1983).

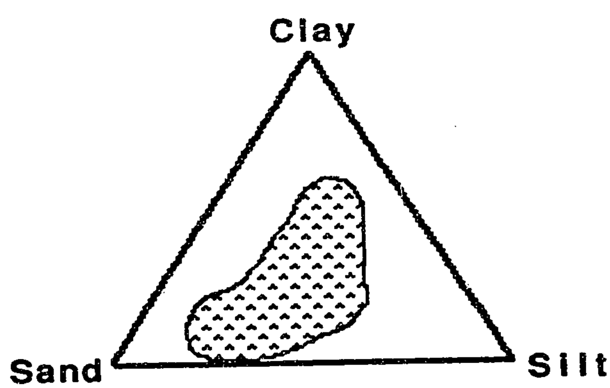


FIG. 3.1b. Matrix grain size distribution envelope for glacigenic diamictons from the Western Canadian Sedimentary Lowland. Modified after Scott (1976).

widespread geographic areas (White 1972, Scott 1976, Kemmis et al. 1979), or change systematically in the direction of ice movement (Gross and Moran 1976). The fine fraction of undisturbed tills can have consistent properties particular to a given glacial advance (McGown 1971, Boulton and Paul 1976), but this may not be the case where the parent rocks are soft and varied (Dreimanis and Vagners 1971).

Processes such as the nature of glacier flow tend to produce uniformity of the debris in transport. Processes that depend on smaller scale variations, such as the form and geology of the glacier substrate and the position and types of deposition, tend to produce local variations. Properties of glacigenic diamicton derived from the first group of processes are more readily predictable, but the second group superimpose variations, causing a broad scatter of results and making prediction difficult (Boulton and Paul 1976). Many of the basic geotechnical properties of till are acquired during erosion and transport when initial mineralogy and grain size are determined. Post-depositional processes of wetting, drying, freezing, mass movement and weathering, considerably affect geotechnical properties. Together, these processes determine grain size distribution, state of consolidation and the presence of joints, which are reflected in geotechnical parameters such as the Atterberg limits, angle of friction, cohesion, void ratio, permeability and coefficient of consolidation (Boulton and Paul 1976; Fig.

21). The character of the dominant fraction of glacigenic diamictons, usually the fine fraction, and the fabric, including stone orientation, layering, fissuring and jointing, are the most indicative of the engineering behavior and variability of the sediment (McGown and Derbyshire 1976).

The fine fraction tends to dominate the engineering behavior of cohesive sediment. Casagrande (1948) showed that a constant relationship exists between plasticity index and liquid limit for a wide variety of sedimentary clays of low carbonate and organic content (Appendix A). The Atterberg limits can be correlated with the engineering properties and behavior of undisturbed fine grained sediment because they are affected by the same factors: chemical and mineralogical composition, size and shape of the sediment particles, ions in the porewater, the amount and grain size of organics present and the stress history of the deposit. Properties such as compressibility, permeability and strength, as well as the limits, depend on the water films present on the sediment particles. The liquid limit increases with increase in clay content, organic matter content or cation exchange capacity, and a decrease in particle size (Seed et al. 1964a,b). Residual shear strength of natural sediments decreases with increasing plasticity index (Voight 1973).

Boulton and Paul (1976) suggested that Atterberg limits are good quantitative indicators of the basic properties of till. They showed that the limit values for englacial debris and unaltered lodgement till fit relatively closely to a straight line which they called the T-line (Fig. 3.2). With increasing clay content points are located farther to the right along the T-line. Melt-out till occupies a field similar to that for englacial debris and lodgement till from the same glacier. When depositional and post-depositional processes produce a grading which is substantially different from that of the parent englacial debris, points plot away from the T-line. The presence of permeable horizons may allow better drainage and faster consolidation and causes the sediment to plot away from the T-line.

Lodgement till may undergo subglacial deformation and remoulding in response to local differences in vertical loading or very small effective stress conditions due to high water pressures. A two-layer structure can thus be produced, with a lower, denser, overconsolidated horizon of lower water content and compressibility, and an upper, soft, weak horizon of high void ratio, natural water content and compressibility (Boulton and Dent 1974). Remoulded lodgement till has lower strength and a lower angle of internal friction than in its undisturbed state, a result of disturbance of the original efficient packing of particles produced during the lodging process (Boulton and Paul 1976). Density contrasts between the two layers can be rapidly removed post-depositionally, although the lower layer tends to retain a platy structure (Boulton and Dent 1974).

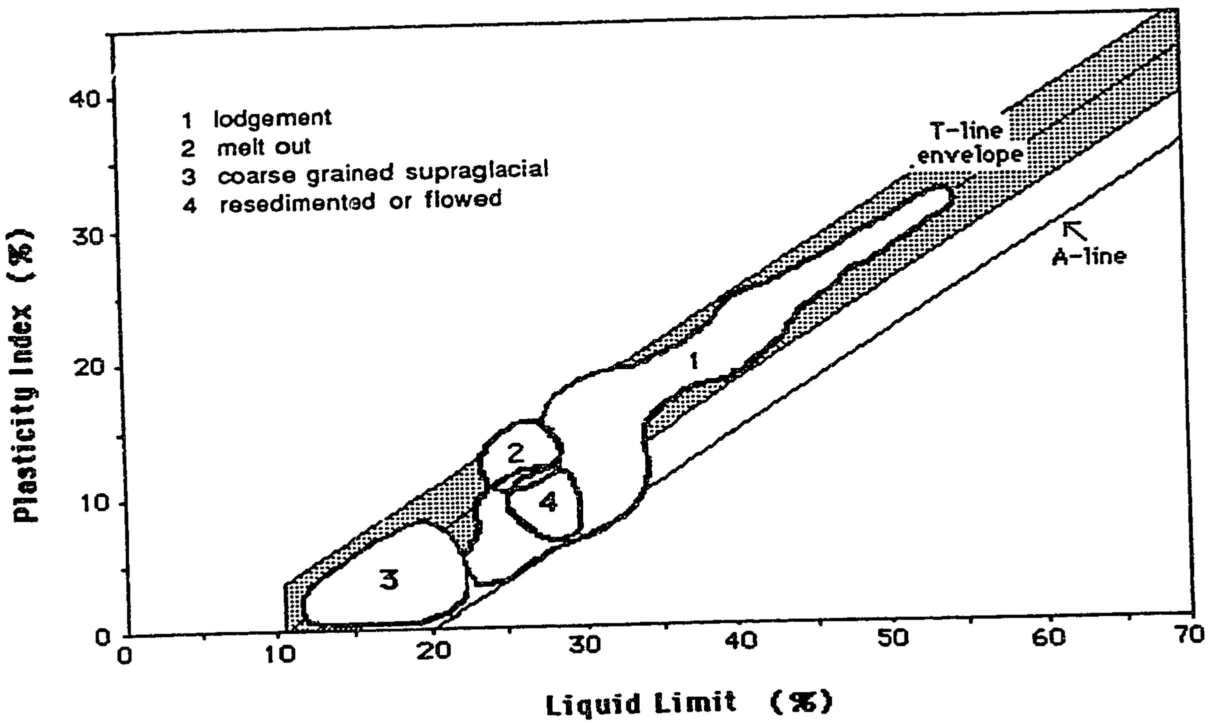


FIG. 3.2. Distribution of various types of glacigenic diamicton matrix on the plasticity chart. T-line represents the distribution for englacial debris and undisturbed lodgement till. Modified after Eyles and Boulton, unpublished data, in Sladen and Wrigley, (1983).

When melt-out till is first released from debris-rich ice masses it possesses a high void ratio which is then reduced rapidly under small overburden pressures. Downslope movement of melt-out till forms flow diamicton.

Subaerial flow diamictons are made up of two elements of very different properties. A little-displaced unremoulded massive diamicton has not been subject to surface processes. A far-travelled fluid slurry has undergone frequent failure and remoulding, and has had water sorting on the surface, resulting in a layered sequence of diamictons and fluviatile sediments. The fluid flows, similar to subaqueous flows, show large variations in grain size distribution, some enriched in silt and clay and some depleted in silt and clay, resulting in a greater variation in liquid limit and plasticity index.

The influence of the weight of overriding ice on the consolidation characteristics of subglacial deposits depends on the water pressure conditions below or at the margins of the glacier (Milligan 1976).

Epigenetic deformation or resedimentation can obliterate contacts between original sediment units and together with weathering, can create geotechnical units that are homogeneous over a range of parent materials (Morgenstern and Cruden 1979). Post-depositional alteration of diamicton properties can occur through changes in the water table, freezing and thawing, slumping and remoulding and changes in grain size composition by removal of fines by percolating water. Supraglacial sediments are very susceptible to downslope movement which removes any contrasts between the properties of melt-out till and flow diamicton. Dessication reduces void ratios by increasing suction stress and causing overconsolidation, leading to the formation of joint planes (Soderman and Kim 1970). Suction stress induced in advance of the freezing front in a soil causes overconsolidation and formation of lenses of segregated ice. Thawing of ice lenses causes closely spaced subhorizontal fissures to form. Downward percolation of water in stabilised diamicton may transport fine grained particles, decreasing the cohesion and increasing the frictional strength at the surface but producing a silty horizon of higher cohesion at depth.

Jointing in clayey sediments reduces their strength (Terzaghi and Peck 1948), and is common in overconsolidated sediments. Joints in lodgement till below the upper massive remoulded horizon appear to be related to unloading and shearing, with a platy structure composed of sub-horizontal joint planes with slickensides in the direction of ice movement. Slickensided shear surfaces can also be found in failed dessicated supraglacial diamicton. Sub-vertical polygonal dessication and horizontal ice segregation lens jointing can be formed in subglacial and supraglacial diamictons.

Weathering horizons can help distinguish deposits of separate advances (Rominger and Rutledge 1952, White 1972). Surface weathering of glacigenic diamicton includes oxidation, hydration, leaching of soluble materials (mainly carbonates), mechanical disintegration of particles, fracturing and downward movement of fines (Willman et al. 1966, Smith 1968, Christiansen 1971, White 1972, McGown et al. 1975, Quigley 1975, Quigley and Ogunbadejo 1976, Eyles and Sladen 1981). It produces a wider grading envelope, an increased scatter in the values of geotechnical properties and a higher intensity of fissuring (McGown et al. 1975). The net effects of weathering, summarised by Sladen and Wrigley (1985), are: 1) increased silt and clay contents due to mechanical disintegration and resulting increased plastic and liquid limits and plasticity index, 2) increased clay content and activity due to formation of secondary clay minerals, increasing the plasticity, and 3) increased moisture contents and higher liquidity indices. Quigley (1975) showed that most glacigenic diamictons soften over time due to weathering processes. Weathering of the upper part of a glacigenic diamicton package commonly results in reduction of strength and density (Olmsted 1968, Sladen and Wrigley 1985). Dessication can initially strengthen some diamictons, but ultimately other factors reduce the strength.

Fookes et al. (1975) found that N values in glacigenic diamictons can be more dependent on grading than on relative density. The coarsest sediment had the highest N values, and the finest sediment had the lowest N values. N values in glacigenic diamictons are usually in the range between 10 and 100, but values higher than 100 are not uncommon, due to the presence of boulders (Stroud and Butler 1975). Dreimanis (1976) demonstrated a weak relationship of increasing penetration resistance with decreasing moisture content in a given glacigenic diamicton. Stroud and Butler (1975) have shown that N also has a rough correlation with the undrained shear strength for cohesive glacial sediments, although the impossibility of absolute standardisation of the test, as well as the varied nature of cohesive sediments, precludes the existence of a universal relationship between N and the shear strength. In a local geographic area, however, such a relationship for given sediment types may be established (Ireland et al. 1970). Pocket penetrometer and unconfined compressive strength test results for cohesive sediments usually show a similar relationship as blow counts to density and shear strength (Terzaghi and Peck 1948).

E. Mapping of the Distribution of the Sediments

The borehole information was used to construct isopach and contour maps of sedimentary units using the Apple MacIntosh inverse distance contouring program MACGRIDZO, Version 1.02, Rockware Inc., 1987. In the inverse distance gridding method, an area is divided into a grid and parameter values for each grid square are averaged from a chosen number of nearest neighbors. The value of a point is weighted with the weight decreasing with increasing distance from the centre of the grid square, according to the formula:

$$Z\ cell = \frac{\text{Sum of}\left(\frac{Z\ point}{distance^{n}}\right)}{\text{Sum of}\left(\frac{1}{distance^{n}}\right)}$$

The data points had an irregular distribution in the map area (Fig. 5.1, in pocket). A grid composed of 200 by 200 map-scale metre cells was used. In order to reduce the distortion for areas of the map having little or no data, only two nearest neighbors were used in averaging the values for each grid square. The value 4 was used for the exponent "n", to increase the weighting on the nearest single point. As a result of averaging, the contours do not honour all data point values. Contours and isopachs were smoothed three times.

Cross sections were constructed through areas with a high density of data points and boreholes to bedrock.

CHAPTER IV
REGIONAL STRATIGRAPHY: SECTION DESCRIPTIONS AND INTERPRETATIONS

A. Introduction

Continental Laurentide ice originating on the Shield reached its southwestern maximum limits in Alberta (Dyke and Prest 1987). The bedrock surface is buried by thick sequences of sediments which consist of preglacial, glacial and postglacial material. In Edmonton, the Big Bend and Clover Bar areas (Fig. 1.1) yield good exposures.

By establishing the stratigraphy and correlating sediments from interpreted field sections with borehole sediment units, the genesis of sediments encountered by drilling can be inferred in areas such as central Edmonton where abundant drilling information and few sediment exposures are available.

B. Big Bend

The Big Bend is a cutbank developed by a large meander of the North Saskatchewan River on the southwest side of Edmonton (SE-16-52-25W4), (Fig. 1.1). The river level is approximately 50 m below the clifftop elevation of 667 m a.s.l. Sediment outcrops occur sporadically along a length of about 500 m of the north bank. The following unit descriptions are from Section A (Fig. 4.1).

1. UNIT 1: CLAYSTONE

Description

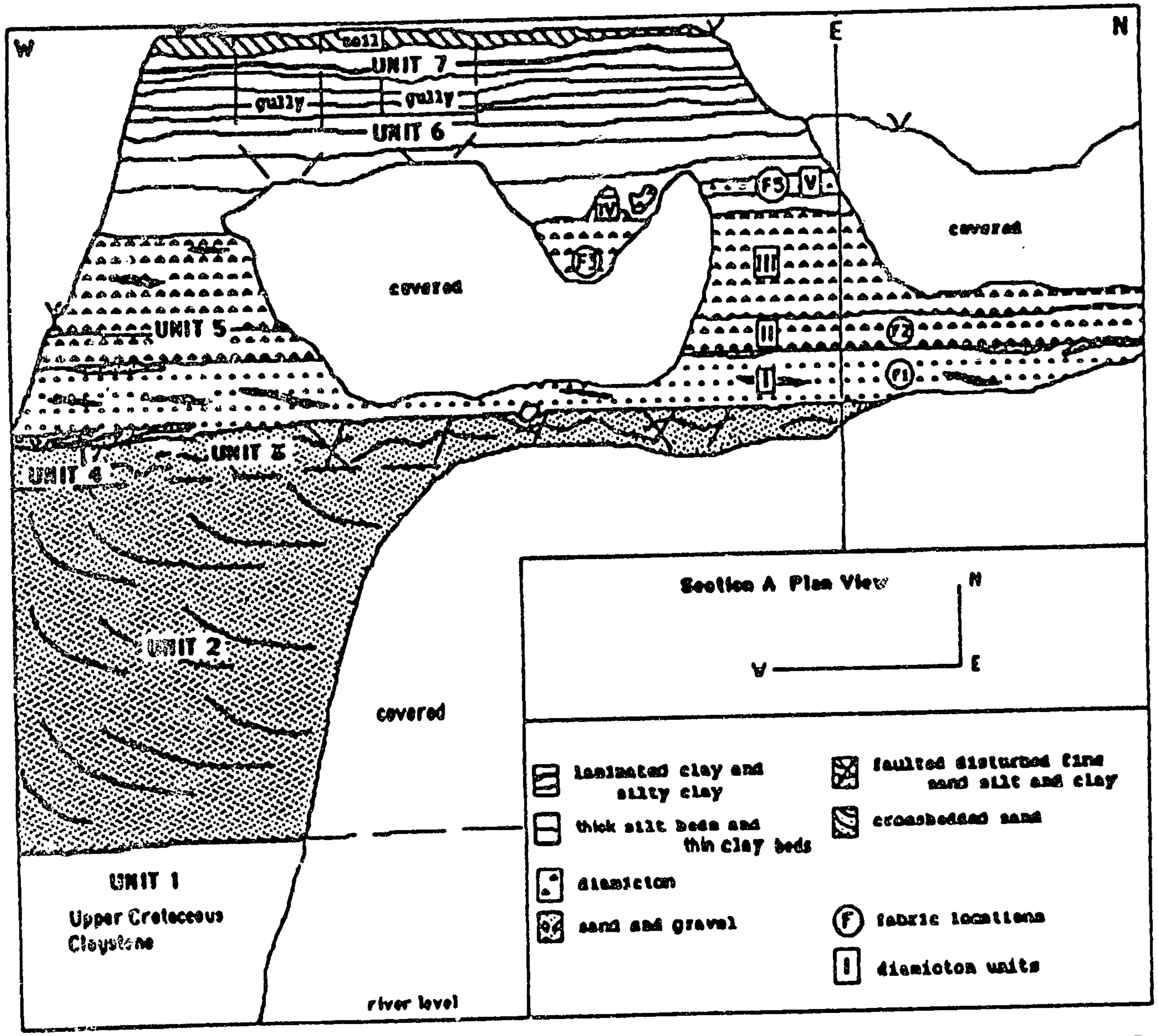


FIG. 4.1. Schematic diagram of Big Bend Section A. Height 50 m. Elevation of top of section 667 m a.s.l.

Weakly-consolidated claystone, considered bedrock, extends to approximately 9 m above river level. It consists of moist, (all references to moisture are used according to the scale shown in Appendix A), soft (all references to hardness are used according to the pocket penetrometer scale shown in Appendix A), plastic (LL 83, PI 59), dark grey (10YR 4/1 m) claystone, composed of 18% sand, 29% silt, and 53% clay (Unified Soil Classification (USCS) CH). A whitish-grey (no Munsell colour) surface coating of salts is present in places on the rounded outcrop face. The upper contact with overlying sand dips west at an angle of a few degrees, and is sharp and erosional.

Interpretation of Unit 1

Unit 1 is classified in the Upper Cretaceous Horseshoe Canyon Formation (Green 1972). The North Saskatchewan River meander has intersected the buried preglacial Stony Valley eroded into this unit. The thalweg of the Stony Valley was mapped by Carlson (1967) to the west of Big Bend and is oriented roughly southwest-northeast.

2. UNIT 2: CROSSBEDDED SAND

Description

Unit 2 is 22 m thick, thinning eastward in the Big Bend cutbank as the underlying bedrock contact rises.

The lower contact with claystone is sharp and erosional. The unit consists predominantly of dry to slightly moist, loose to compact, brown (10YR 5/3 m) to grey-brown (10YR 5/2 m), quartzitic, fine to medium grained well-sorted sand, with approximately 90% sand and 10% silt and clay (USCS classification SP). Large scale trough crossbedding, planar tabular crossbedding and plane bedding have bed thicknesses of several metres, thinning up section (Plate 4.1). Thin beds of coarse sand and some pebbles up to several centimetres thick consisting of local lithology coal, shale and ironstone, occur at the base or within some crossbedded units. The palaeocurrent direction from crossbeds is highly variable, but appears to be dominantly to the north-northeast. In the upper 2 to 3 m of the unit the sand becomes finer grained and silty, and the crossbedding becomes smaller scale. The upper contact is diffuse and gradational with sand of unit 3.

Interpretation of Unit 2

Unit 2 is interpreted to be a fluvial deposit, from the crossbedding and channel lag deposits. Similar features have been observed in modern sandy braided streams (Cant and Walker 1984). The sand contains no Shield provenance material and is located within the buried preglacial Stony Valley, and therefore belongs to the youngest preglacial deposits, the Saskatchewan Gravels and Sands, as defined by Stalker (1968).

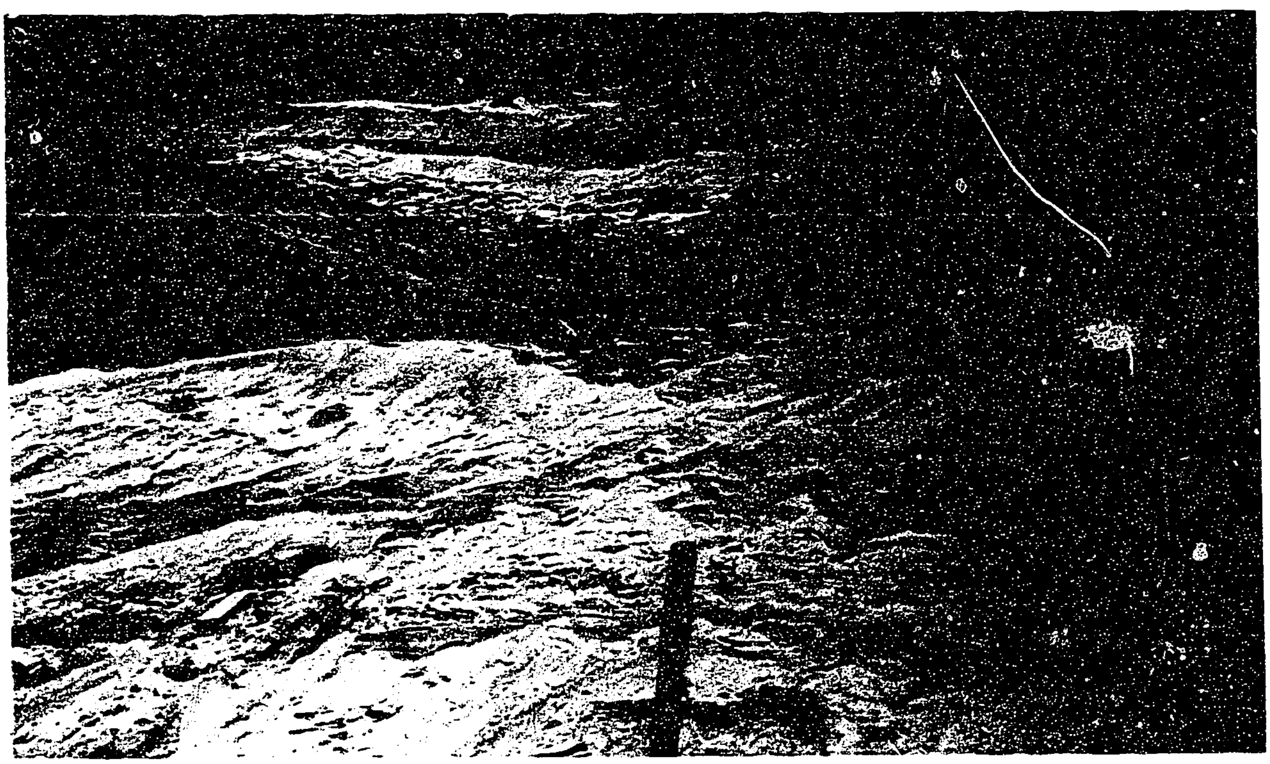
3. UNIT 3: SAND CONTAINING LENSES AND BEDS OF SILT AND CLAY

Description

The thickness of unit 3 is highly variable, ranging between 0.2 and 1 m, with a mean thickness of 0.5 m.

Well sorted sand of unit 2 grades up into less well

PLATE 4.1. Crossbedded sand of unit 2 at Big Bend. Blue handle of pick is 20 cm long.



sorted sediment of unit 3. Unit 3 consists of fine to medium grained, moderately sorted sand, with 13% clay, 37% silt, and 50% sand (USCS classification SM), containing lenses and beds of silt and clay, which commonly exhibit disturbed wavy bedding. The unit is dry and compact. It is cemented and dense in places directly beneath diamicton of unit 5. The colour is light brown (10YR 4/3 d), with some white (no Munsell colour) salt encrustation. Low angle planar crossbeds are defined in places by coal laminae or iron oxide staining. The dominant palaeocurrent direction determined from crossbeds is to the east. Shield provenance minerals are present. Unit 3 is generally overlain by diamicton of unit 5, with a sharp erosional contact. In places it has a sharp erosional upper contact with discontinuous sand and gravel containing diamicton lenses (unit 4). The upper contact with both units 4 and 5 is smooth and subplanar on a scale of tens of metres, and undulatory on a centimetre scale.

Faults are common and consist mostly of normal faults with displacements of up to 2 cm. They are concentrated in the top 15 cm of Unit 3, some extending down into the top of Unit 2. Reverse faults show overthrust displacement to the west-southwest.

Interpretation of Unit 3

Sand, silt and clay of unit 3 are interpreted to have been deposited by fluvial processes of fluctuating energy, indicated by the crossbedding and variable sediment types. The sediments may have been deposited near the margin of an ice sheet because they contain material of Shield provenance, and Laurentide ice advancing generally from the northeast up the regional slope would have to be in the immediate area before material transported by the glacier could become deposited in the fluvial systems. Overriding ice eroded and sheared the sediments beneath, which may have been frozen. Thrust faults were formed by shear and normal faults were caused by ice loading. The hard cemented upper part of the unit is probably the result of translocation of clay and carbonate downward from overlying diamicton units.

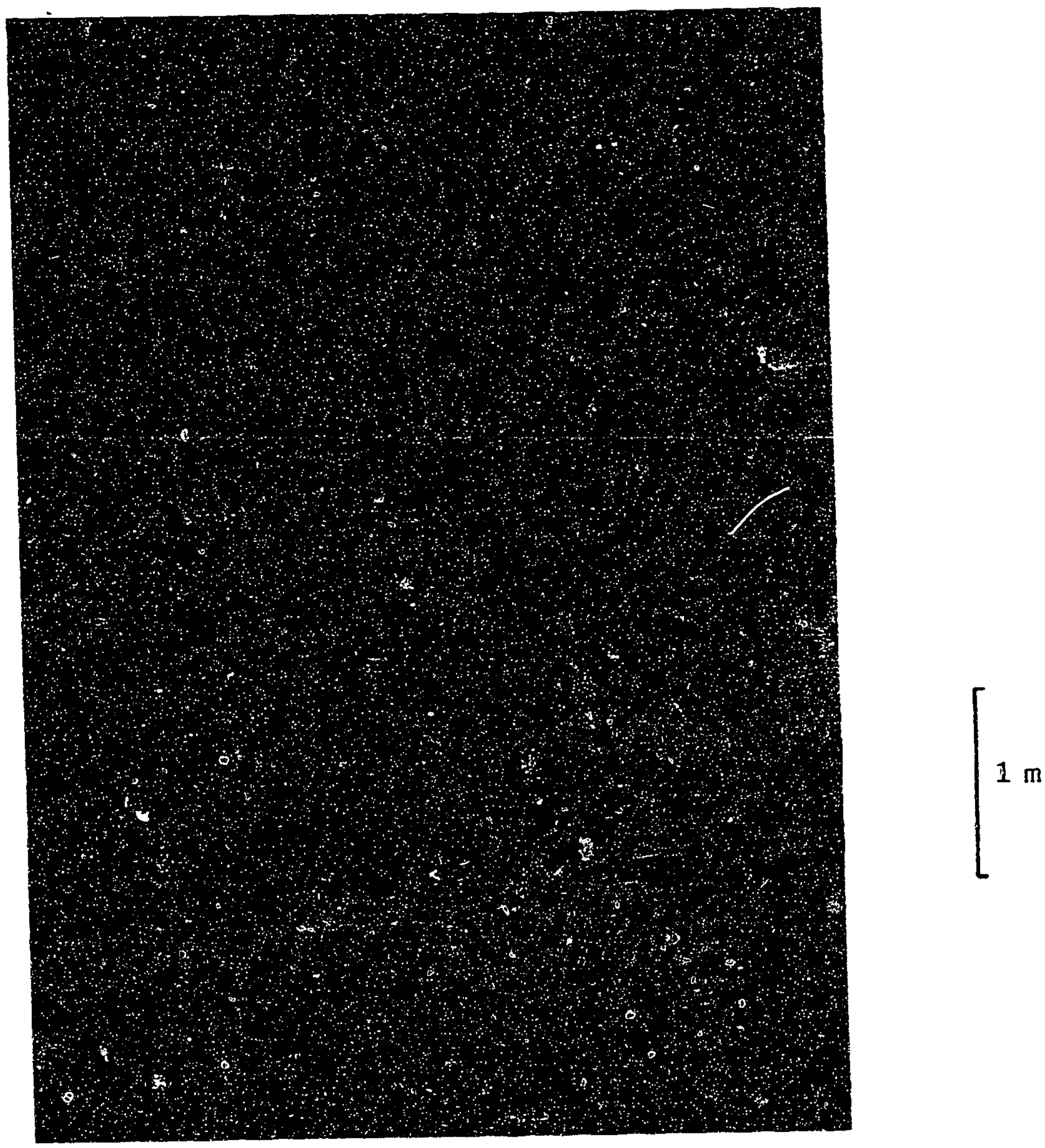
4. UNIT 4: SAND AND GRAVEL CONTAINING DIAMICTON LENSES

Description

Unit 4 is discontinuous, with a mean thickness of 0.4 m.

On the western side of Section A, a long, thin lens of poorly sorted sand and gravel (USCS classification GM), has a length of approximately 12 m and a mean thickness of 0.4 m (Fig. 4.1 and Plate 4.2). The lens has a sharp, slightly convex, erosional lower contact with disturbed sand, silt and clay of unit 3. The upper contact with diamicton of unit 5 is sharp and subplanar. A diamicton lens approximately 0.06 m thick and 2 metres long is interbedded with the sand and gravel, but is in contact with overlying diamicton at its eastern end. The unit was inaccessible for sampling. The diamicton is generally greyish brown (no Munsell colour), and yellow-brown (no Munsell colour) iron oxide stains are located at the edge of the sand and gravel

PLATE 4.2. Lower part of the diamicton complex (unit 5) at Big Bend. Sand of unit 3 is overlain by a sand and gravel lens containing diamicton lenses of unit 4, which is overlain by Diamicton I and Diamicton II of unit 5.


1 m

and around the diamicton lens.

Interpretation of Unit 4

The sediments of unit 4 are interpreted to have been deposited in a glaciofluvial environment, probably an ice-marginal or subglacial channel, as indicated by the lens-shaped deposit with an erosional lower contact and sharp upper contact with diamicton, and the diamictons within the sand and gravel. Diamicton debris flows can originate from debris released from melting ice at the snout of the glacier or from the base of the glacier, and can become interbedded with sand and gravel (Lawson 1979).

5. UNIT 5: DIAMICTON COMPLEX

5a. DIAMICTON I

Description

Diamicton I is the lowermost diamicton of three which form a diamicton complex (Fig. 4.1 and Plate 4.2). It is 2.5 m thick.

The lower contact with sand, silt and clay of unit 3 is sharp and erosional. The diamicton is dry, very hard and dark grey-brown (Table 4.1), with the surface oxidised brown (no Munsell colour). It is matrix-dominated, with a sandy matrix (Fig. 4.2) that fines up and has a low to medium plasticity (Table 4.1). The USCS classification is CL. The lower part of Diamicton I deviates to the left and below the T-line, which indicates some sorting or dilution, and the upper part of Diamicton I plots close to the T-line, more typical of debris in transport within a glacier (Fig. 4.3).

	Munsell Colour	W %	PP kPa	Matrix			% Coarser Than Sand	LL %	PI %	Thickness m	Jointing
				Clay	Silt	Sand					
Diamicton Y	brown 10 YR 5/3 d	2.0 w	>480 d	28.5	33.5	38.0	25	30.5	16.5	0.4	moderate subvertical random secondary rectangular
Diamicton IV	light brown grey 10 YR 6/2 d	2.0 w	>480 d	28.0	39.5	32.5	8	38.0	20.5	0.5-5.0	strong subvertical, curved, secondary blocky
Diamicton III	dark grey brown 10 YR 4/2 m	5.5 w	375 m	25.5	29.5	45.5	12	29.0	16.5	5.0	moderate columnar secondary blocky
Diamicton II	very dark grey brown 10 YR 3/2 d	1.6 w	>480 d	30.5	28.5	41.0	5	32.0	14.5	1.0	strong closely spaced columnar
Diamicton I	dark grey brown 10 YR 4/2 d	1.6 w	>480 d	23.5 u 18.5 l	30.5 u 38.5 l	46.0 u 43.0 l	8	27.5 u 23.5 l	14.5 u 7.5 l	2.5	moderate columnar secondary blocky

TABLE 4.1. Properties of diamictons at Big Bend. W = water content, PP = pocket penetrometer, LL = liquid limit, PI = plasticity index, kPa = kilopascals, u = upper unit, m = middle unit, l = lower unit, w = weathered. For penetrometer and colour: d = dry, m = moist.

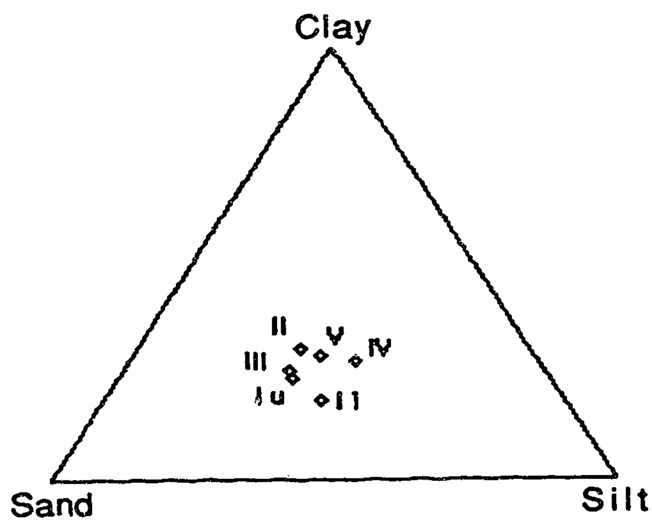


FIG. 4.2. Matrix grain size distributions of diamictons at Big Bend. Diamictons are numbered I - V. l = lower unit, u = upper unit.

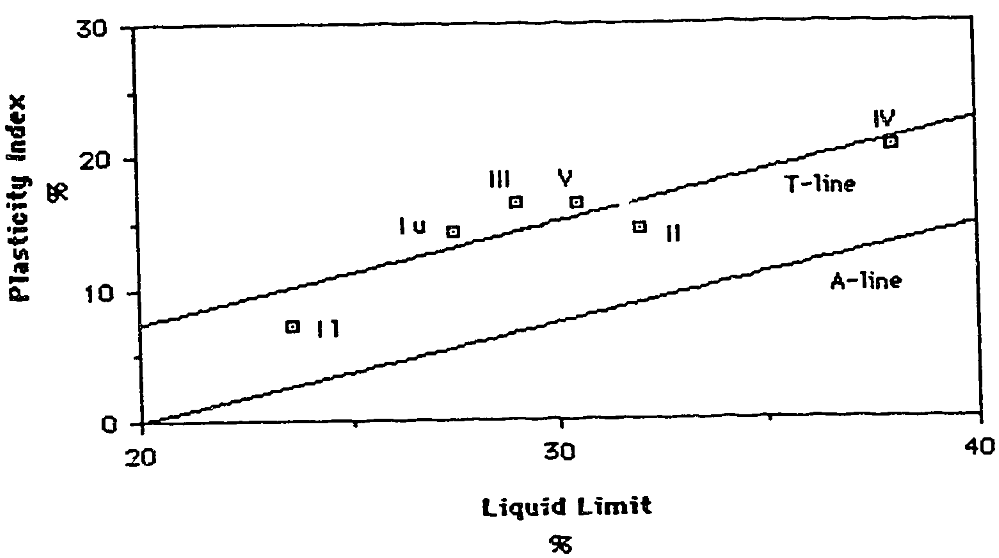


FIG. 4.3. Atterberg limits of diamictons at Big Bend. u = upper unit, l = lower unit. Diamictons numbered I - V.

Large clasts consist of 5 to 10% angular to subrounded pebbles and cobbles with rare boulders to 0.5 m in diameter. Sandstone, siltstone, quartzite and coal are the dominant clast lithology, with abundant igneous, metamorphic and carbonate clasts. Abundant coal pieces are 1 cm or less in size, with some larger ones to 15 cm in length. Striated clasts are more common at the bottom of the unit, but are generally scarce. Cobbles occur along the lower contact, extending down into underlying sand, silt and clay of unit 3. Some are elongated northeast-southwest and are bullet-shaped, with noses pointing to the northeast. Accumulations of sediment mantle their western sides, and reverse faults dipping to the east occur in the underlying sediment.

Approximately the lowermost 10 cm of Diamicton I can consist of numerous thin beds of diamicton and sand, attenuated by reverse faults. Lenses of sand 1 to 10 cm thick and up to several metres in length occur throughout the rest of the unit. Most are slightly biconvex, have distinct contacts with surrounding diamicton, dip between 5 and 10 degrees to the northeast and consist of structureless, medium grained, moderately sorted, quartzitic sand. A lens near the bottom of the unit is relatively short and thick, contains crossbedded sand, and has a convex lower contact and planar top. Many of the sand lenses are iron-oxide stained. There are also very sandy zones that have diffuse contacts with surrounding diamicton. Lenses which occur along the upper contact of

Diamicton I with Diamicton II consist of crudely bedded, poorly sorted sand and gravel.

The upper contact is sharp and sub-planar, with small scale undulations. The conformable contact separates diamictons of different colour, joint density, clast content and number of lenses of sorted sediment (Plate 4.2).

A single fabric from the centre of Diamicton I has a strong, unimodal, northeast-southwest trend orientation and low plunge angles (Fig. 4.4a).

Weak to moderate, random, subvertical joints occur throughout the diamicton with a mean spacing of approximately 0.5 m. Weak, blocky, secondary fractures are present. Iron oxide staining occurs on fracture surfaces.

Interpretation of Diamicton I

Diamicton I is interpreted to have been subglacially deposited, indicated by the strong unimodal fabric aligned northeast-southwest, parallel to know indicators of regional ice movement. The sandy matrix texture is most likely due to the incorporation of local substrate material by the ice, indicated by the erosional lower contact.

A component of lodgement till may be present at the base of the diamicton in places, indicated by a concentration of striated clasts and the bullet-shaped cobbles concentrated along the lower contact, with their a-b axes aligned parallel to the direction of regional ice movement (cf. Boulton 1971). Sand lenses with planar tops probably represent overridden subglacial meltwater channels

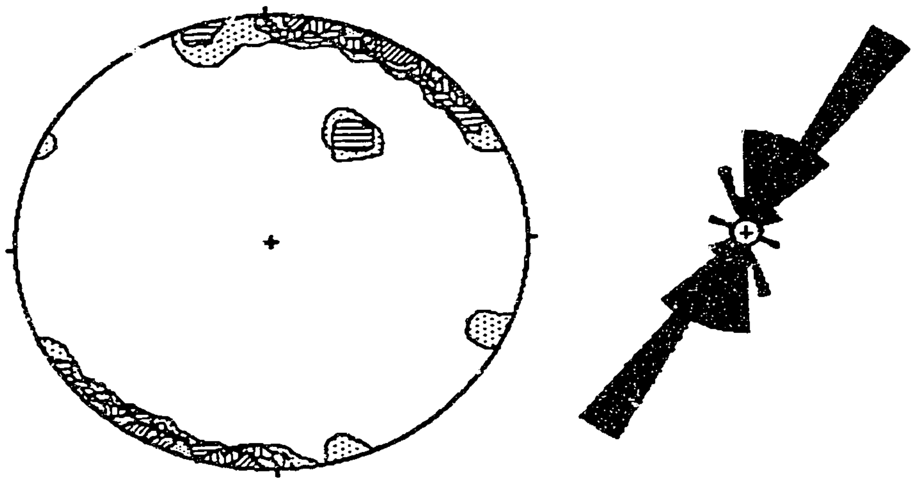


FIG. 4.4a. Diamicton I. N = 25. Mean orientation 024.2. Mean plunge 4.4.° S1 = 0.82, S2 = 0.15, S3 = 0.04.

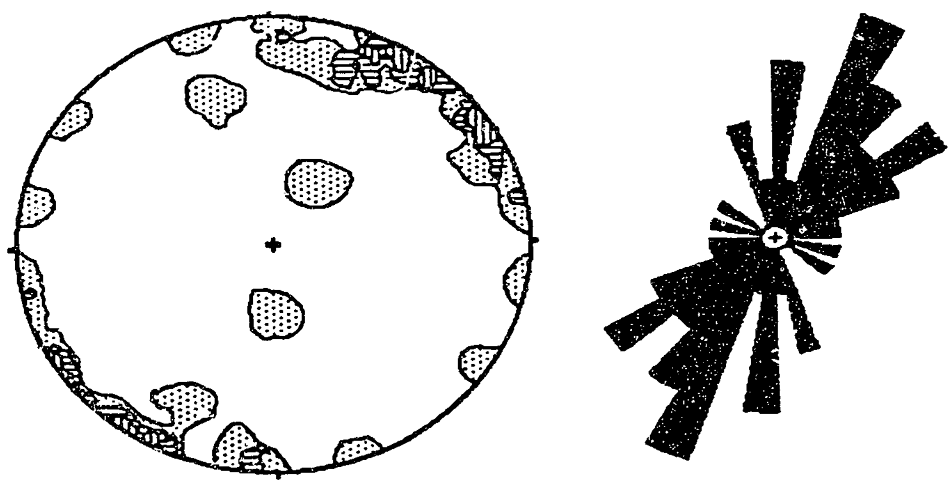


FIG. 4.4b. Diamicton II. N = 25. Mean orientation 036.6. Mean plunge 5.6.° S1 = 0.68, S2 = 0.23, S3 = 0.09.

FIG. 4.4. Pebble fabric contour and rose diagrams for diamictons at Big Bend. N = number of observations. S1, S2, S3 = eigenvalues. 4-7%; 8-11%; 12-15%; 16-19%; 20-24%.

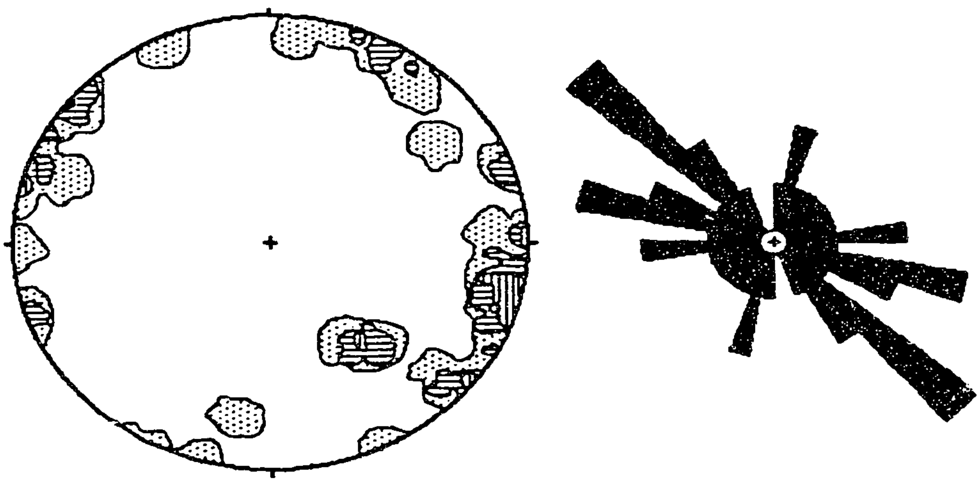


FIG. 4.4c. Diamicton III. N = 25. Mean orientation 109.3. Mean plunge 9.5.° S1 = 0.59, S2 = 0.34, S3 = 0.07.

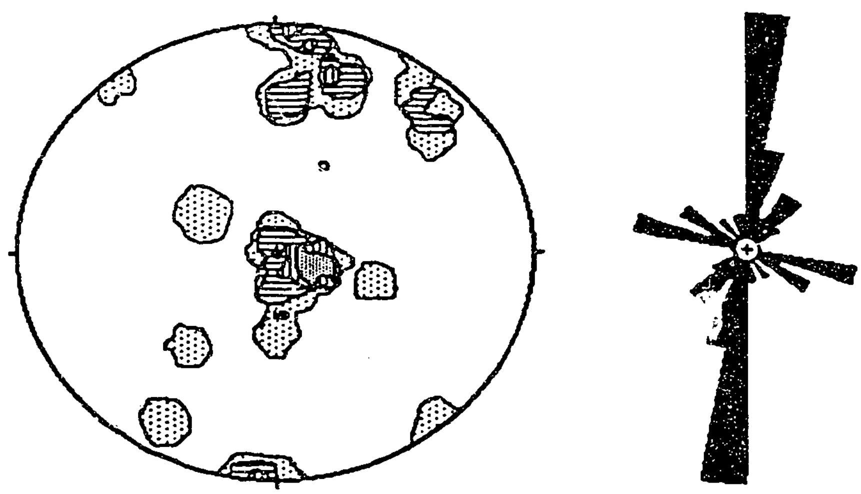


FIG. 4.4d. Diamicton IV. N = 25. Mean orientation = 026.3. Mean plunge 56.0.° S1 = 0.51, S2 = 0.40, S3 = 0.09.

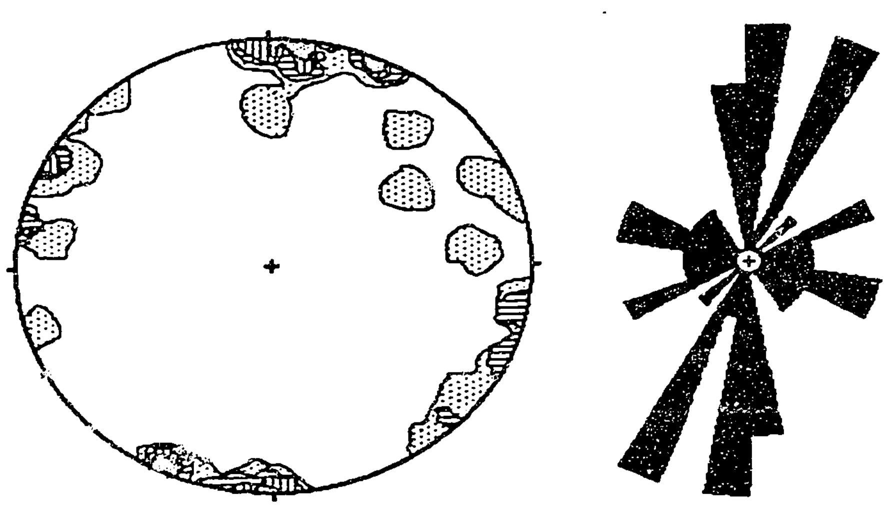


FIG. 4.4e. Diamicton V. N = 25. Mean orientation = 012.5. Mean plunge 7.3.° S1 = 0.55, S2 = 0.41, S3 = 0.04.

(cf. Eyles et al. 1982). Thin sand stringers at the base may have formed by shearing at the base of the glacier (cf. Krüger 1979), or from the release of water during local melt out accompanying the lodgement process (cf. Rose 1974).

Most of Diamicton I was probably deposited by melt out, indicated by the abundance of non-tectonically disturbed lenses of sorted sediment (cf. Haldorsen and Shaw 1982), the presence of friable clasts such as coal (cf. Shaw 1982), the low plunge angles of the pebble fabric dipping both up and down ice (cf. Lawson 1979, Boulton 1971), and the texture of the upper part of the unit which plots in the range of debris in transport on the T-line (cf. Boulton and Paul 1976). Melt out can occur locally where the base of the glacier is separated from its bed (Shaw 1987). Dipping sorted lenses may have formed from alternating debris-rich and debris-poor bands in the ice preserved in melt-out till, with debris-poor layers forming dipping sorted lenses upon melting (cf. Sugden and John 1976).

Blocky fracture of the diamicton is likely caused by consolidation of the sediments. The random columnar joints are probably the result of stress release along the valley wall during downcutting by the North Saskatchewan River (cf. Matheson and Thomson 1973, Babcock 1974, Catto 1984).

5b. DIAMICTON II

Description

Diamicton II thins slightly to the east, with a mean thickness of 0.75 m (Plate 4.2).

The lower contact with Diamicton I is sharp, conformable, and sub-planar, with minor small scale undulations. Diamicton II is dry, hard and very dark greyish-brown (Table 4.1). The surface is not oxidised, but iron-oxide stains are present on fracture surfaces. The diamicton is massive and matrix-dominated, with a medium plastic sandy matrix that is not graded and is more clayey than that of Diamicton I (Fig. 4.2 and Table 4.1). The USCS classification is CL. Diamicton II plots in the range of debris in transport on the T-line (Fig. 4.3).

There are approximately 5% subrounded to subangular pebbles and cobbles to 20 cm in diameter. Sandstone, siltstone and quartzite are the dominant clast lithology, with abundant igneous and metamorphic, and some carbonate and coal clasts. Striated clasts are scarce.

The upper contact is distinct to sharp, conformable and sub-planar with overlying Diamicton III. Sand and gravel lenses, to approximately 5 cm in thickness and 30 cm in length, occur along the upper contact in places.

A single pebble fabric from the centre of the unit shows a moderately strong, unimodal, northeast-southwest trend orientation and dominantly low plunge angles (Fig. 4.4b).

Strong, columnar joints have a mean spacing of 1.5 cm, and some extend up into Diamicton III. The joint planes are approximately parallel (azimuth 285) and perpendicular (azimuth 179) to the outcrop face, and the diamicton breaks apart easily into columns.

Interpretation of Diamicton II

Diamicton II is interpreted to have been deposited subglacially beneath the same glacier which deposited Diamicton I, as indicated by the similar unimodal pebble fabrics parallel to known regional ice movement direction (northeast-southwest) of the two diamictons, and the non-erosional contact between them. The dominant process of deposition of Diamicton II was probably melt out as was interpreted for Diamicton I, because the texture resembles debris in transport (cf. Boulton and Paul 1976), and the presence of friable coal clasts (cf. Shaw 1982), and a non-erosional lower contact, precludes lodgement. The diamicton is therefore a melt-out till, probably relatively undiluted by local substrate material, giving it a slightly finer texture than melt-out till of Diamicton I.

The columnar joints parallel and perpendicular to the outcrop face may have formed from stress release at the outcrop face (cf. Matheson and Thomson 1973, Babcock 1974, Catto 1984), however, the strength and regularity of the jointing suggests that another process such as unloading (cf. Boulton and Paul 1976) caused the jointing, which supports the subglacial interpretation for the origin of the diamicton. The close joint spacing may be because the unit is thinner and the matrix texture is finer grained than the other diamicton units.

5c. DIAMICTONS III AND IV

Description

Diamicton III has a thickness of 5 m.

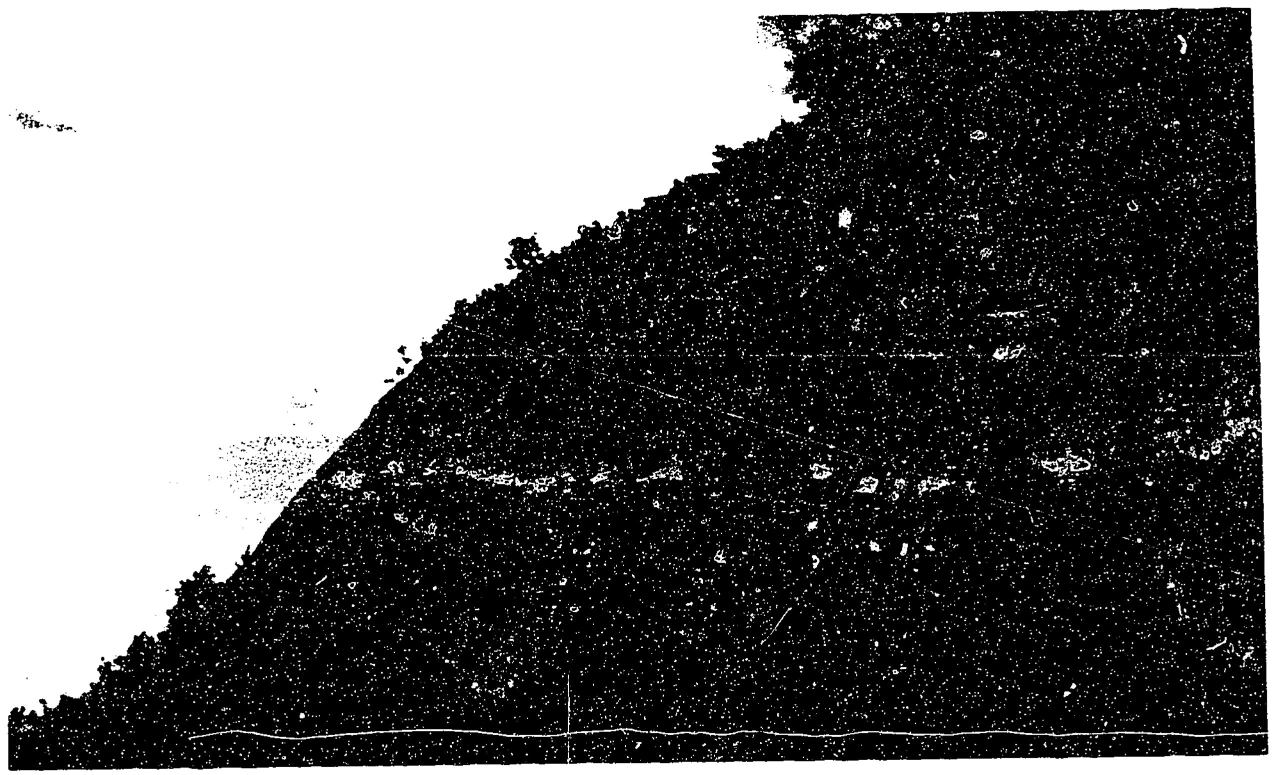
The lower contact with Diamicton II is distinct to sharp, conformable and sub-planar. Small grooves, several centimetres in length and several millimetres wide, on the basal surface of Diamicton III have a northwest-southeast orientation. Diamicton III is slightly moist, hard and dark greyish brown (Table 4.1). It is matrix-dominated, with a medium plastic sandy matrix, and USCS classification CL (Fig. 4.2 and Table 4.1). Diamicton III plots in the range of debris in transport on the T-line (Fig. 4.3).

There are approximately 12% subangular to subrounded pebbles and cobbles to a maximum of 20 cm in diameter, with approximately one third of the clasts consisting of coal or coaly shale up to 7 cm in diameter. Other clast lithology is igneous, metamorphic, sandstone, siltstone, quartzite and minor carbonate. Striated clasts are scarce. Biconvex sand lenses up to 15 cm in width and 10 cm in thickness occur throughout the diamicton. Silt stringers up to several metres long and several centimetres in thickness occur in the top half of the unit, increasing in frequency up section. Within the uppermost metre, sand lenses and silt stringers are deformed and wavy.

The upper contact with silt of unit 6 is generally sharp, and planar to undulating. In places the contact is highly irregular (Plate 4.3) where Diamicton III grades up into diamicton diapirs (Diamicton IV).

A single pebble fabric from 2 m below the upper contact has a moderate, northwest-southeast mode, a weak, northeast-southwest mode and low to moderate plunge angles

PLATE 4.3. Upper part of the diamicton complex (unit 5) at Big Bend, showing columnar jointing in Diamicton III. The diamicton complex has an irregular upper contact with overlying thick silt beds interbedded with thin laminated clay (unit 6).



1 m

(Fig. 4.4c).

Moderately strong, subvertical, columnar joints are unevenly spaced, with a mean spacing of approximately 0.4 m. In places the unit exhibits very strong, regular columnar jointing with a mean spacing of approximately 0.3 m (Plate 4.3). There is also a moderate, blocky, secondary fracture pattern. Iron oxidation stains are present on some joint surfaces.

Massive, conchoidally fractured silt surrounds diamicton diapirs which extend upward from Diamicton III. This discontinuous sub-unit is 1.1 m thick at Section A, but reaches several metres in thickness elsewhere at Big Bend (Section B, Figs. 1.1 and 4.5).

Some diapirs are separated from underlying diamicton and completely surrounded by massive silt. The outer contacts of the diapirs are sharp, irregular, and curved. Diamicton IV, which forms the diapirs, is dry, hard and light brown grey (Table 4.1). It is matrix-dominated, with a plastic silty matrix and USCS classification CL (Fig. 4.2 and Table 4.1). Diamicton IV plots to the right along the T-line relative to other Big Bend diamictons, reflecting its finer texture, with the lowest sand and highest silt contents, however, it is situated on the T-line, indicating it has a grain size distribution typical of debris in transport, which does not reflect its obvious disturbed nature (Fig. 4.3).

There are approximately 8% subrounded to subangular pebbles with long axes to 6 cm, and similar clast lithology

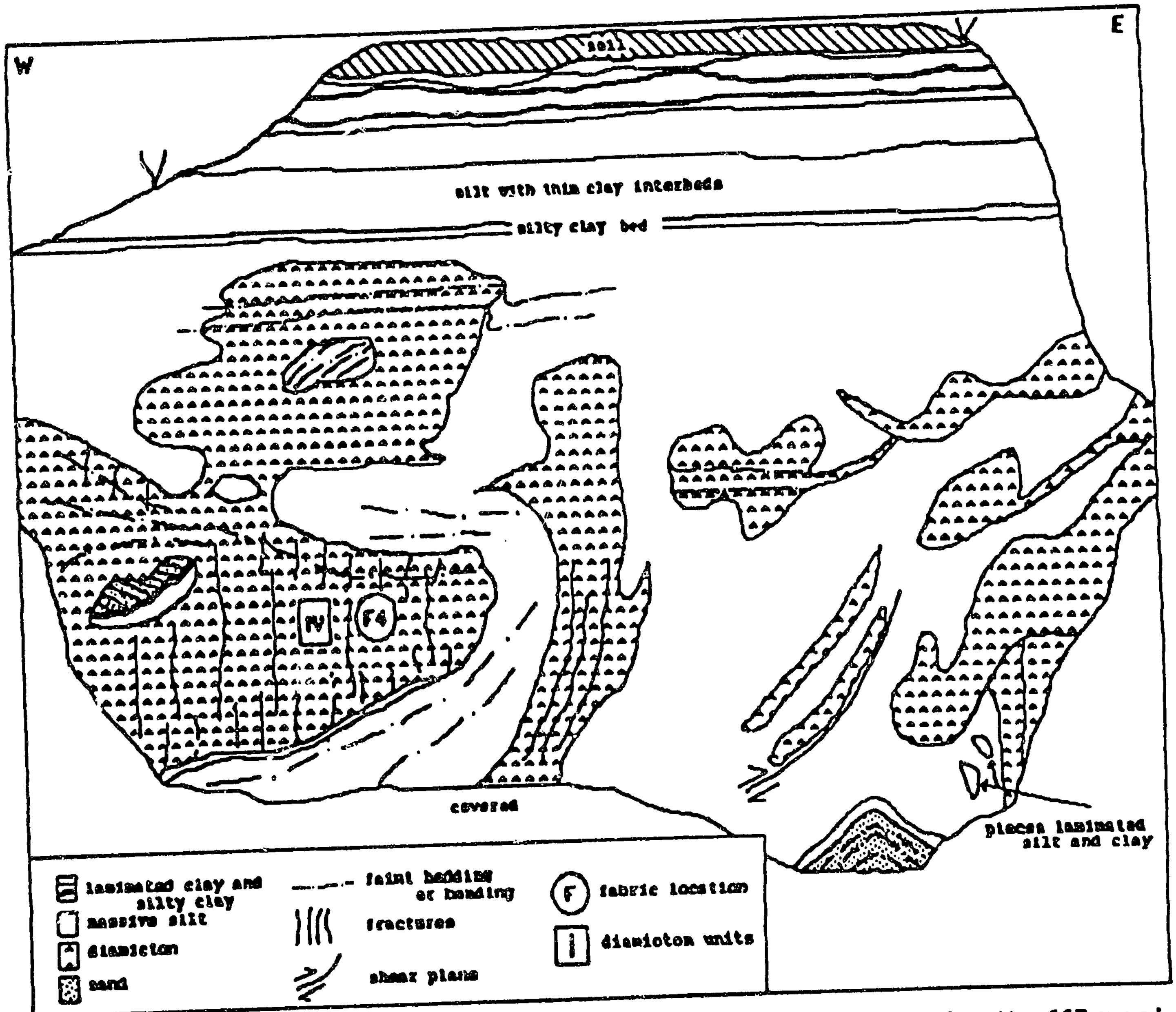


FIG. 4.5. Schematic diagram of Big Bend Section B. Height 7 m. Elevation of top of section 667 m a.s.l.

to Diamicton III. Pieces of massive silt and silt stringers occur within the diapirs. A sand and silt lens, 0.8 m wide and 0.25 m thick, is approximately biconvex in shape and has sharp contacts with surrounding diamicton (Fig. 4.5). Bedding within the lens is slightly distorted.

A single pebble fabric from a diapir at Section B (Fig. 4.5) has a weak, north-south trend orientation and high to vertical plunge angles (Fig. 4.4d).

Diamicton IV has strong, sub-vertical to curved fractures, and secondary, blocky fracture in places.

Interpretation of Diamictons III and IV

Diamicton III is interpreted to have been deposited by debris flows, indicated by the pebble fabric that is not parallel to known regional ice flow direction, with a transverse component and a weak girdle (cf. Rees 1983), and the presence of sand and silt stringers throughout the unit which could indicate sorting and deposition by meltwater on the top of individual flowed units (cf. Lawson 1982). Grooves on the lower contact were probably formed by flowing material in the basal shear zone of debris flows (cf. Lawson 1982). The similar northwest-southeast orientations of the grooves at the base of the unit and the pebble fabric suggests that all of Diamicton III consists of flow diamicton. The thickness of the unit suggests proximity to the source of debris flow material, such as debris melted out of the glacier snout (Boulton 1971), debris released at the grounding line of ice in water (Powell 1981), or debris banks within a proglacial lake

(Kulig 1985).

Formation of diamicton diapirs is interpreted to have been caused by loading of saturated Diamicton III by silt, causing upward low viscosity movement of diamicton and disturbing overlying silt beds. Minor distortion of silt and sand intraclasts during diapir formation indicates that the diamicton was fluid. Saturation of the diamicton was probably caused by the presence of a proglacial lake, into which some of the Diamicton III debris flows may have been deposited. The finer texture of the diapiric diamicton (Diamicton IV) relative to other Big Bend diamictons, is probably due to incorporation of overlying fine grained sediment during diapir formation. The pebble fabric orientations and high plunge angles reflect the orientation of disturbance and the upward movement of the diapirs.

The random columnar jointing of Diamicton III is probably due to stress release along the modern valley side (cf. Matheson and Thomson 1976, Babcock 1977, Catto 1984), however, strong, regular columnar jointing in the upper part of the diamicton complex in places may have resulted from weathering or dessication (cf. Soderman and Kim 1970).

6. UNIT 6: SILT CONTAINING BEDS OF SILTY CLAY AND DIAMICTON V

Description

Unit 6 is 6.6 m thick.

The lower contact with Diamicton III is generally sharp and undulatory, except in where it is irregular due to diamicton diapirs (Diamicton IV) which disturb the silt.

The unit consists mainly of planar silt beds with a maximum thickness of 1.6 m at the bottom, thinning up section (Plate 4.6). The silt is dry, compact, olive yellow (2.5 Y 6/6 d), and has a mean composition of 19% clay, 67% silt, and 14% sand (USCS classification ML). At the base, massive, planar bedded and crossbedded, beds of silt and fine grained sand are interbedded with thin, silty clay beds and with diamicton in places. The silt beds become less sandy up section. Fine grained sand and silt shows ripple drift cross lamination, with palaeocurrent directions to the west. Laminated silty clay beds increase in thickness up section from approximately 1 cm to 10 cm. They are subhorizontal to horizontal, wavy and disturbed or loaded in places, with blocky fractures. The upper contact is gradational with interbedded silt and clay of unit 7. The silt surface is conchoidally fractured, except directly above Diamicton III where it is moist and slumped in places. Rare sub-vertical joints extend through unit 6.

On the east side of Section A, a wedge-shaped bed of Diamicton V has a mean thickness of 0.35 m, with a maximum of 0.45 m, and is interbedded with silt (Fig. 4.1). The diamicton extends laterally for several metres, thinning and pinching out westward. The lower contact is sharp, wavy and erosional with underlying massive and plane bedded silt. Diamicton V is dry, hard, brown (Table 4.1), and weathered light brown on the surface. It is matrix-dominated, with a silty, medium plastic matrix and USCS classification CL (Fig. 4.2 and Table 4.1). Diamicton

V plots close to the T-line in the region of debris in transport (Fig. 4.3). There are approximately 25% rounded to subangular pebbles and cobbles to a maximum diameter of 12 cm, with a predominant clast lithology of quartzite, and some igneous and metamorphic clasts. The upper contact of with massive silt is sharp, wavy and loaded in places.

A single pebble fabric from the centre of the diamicton bed has a moderate north-northeast-south-southwest mode, a transverse mode and moderate plunge angles (Fig. 4.4e).

Random subvertical joints with a mean spacing of 0.3 m are present. In places oblong rectangular fractures several centimetres apart have their greater length dipping approximately 25 degrees to the east and exhibit fracture planes convex downward, resembling a stretched and curved grid.

Interpretation of Unit 6

Planar beds of sandy silt are interpreted to have been deposited by underflow currents or sediment gravity flow in a proglacial lake, as indicated by the ripple drift cross lamination and interbedding with finer grained lacustrine sediments and diamicton beds (cf. Gustavson 1975). Thin, laminated, silty clay beds were laid down by suspension settling between episodes of gravity flow as interpreted by Kulig (1985; facies 12) for sediments near Wetaskiwin, and as observed by Gustavson (1975). The cross lamination indicates that input of sediment into the lake, and therefore the source of meltwater influx, was dominantly in the east, and thinning of the silt beds and accompanying thickening of the clay beds upward indicates that a high rate of silt and sand input into the lake from a proximal source decreased, probably as the ice margin melted or retreated to the east, or as the lake enlarged and deepened.

Diamicton beds are interpreted as having been deposited by subaqueous debris flow, indicated by their interbedding with glaciolacustrine sediments, wedge-shaped geometry, the moderately strong pebble fabric containing a transverse component (cf. Rees 1983), and curved fracture planes that resemble flow features (cf. Evenson et al. 1977).

7. UNIT 7: INTERBEDDED SILT, SILTY CLAY, AND CLAY

Description

Unit 7 is 3 m in thickness.

At the base of the unit, interbedded laminated silty clay and massive silt beds have approximately equal thicknesses of 10 cm. The silt beds thin up section and the unit grades up into rhythmically bedded, graded silty clay and massive clay beds, with some interbedded massive silt layers to 1.5 cm thick. Clay beds at the base of the unit have laminations 3 cm in thickness, thinning upward to 1 mm in thickness. Tops of clay beds have load, fold and rip-up features, where overlain by silt or diamicton. Diamicton pods or lenses up to 5 cm thick and 15 cm long have a silty or sandy matrix and clay intraclasts. In the upper metre of the unit no silt or diamicton lenses are present, and the clay and silty clay are rhythmically bedded. A composite bulk sample of the unit yields 64%

clay, 29% silt, and 7% sand, with a liquid limit of 68% and plasticity index of 42% (USCS classification CH). Within the laminated clays are coal pieces up to coarse sand size and pebbles which deform underlying strata.

The upper 0.45 m has undergone intense pedological modification, resulting in a thin, loose, loamy, brown Ahe horizon overlying a Bt horizon with clay skins. Roots reach a maximum depth of 2.5 m. Below the soil, the surface of the clay is dry and hard, pale brown (10 YR 8/3 d), and coated with light grey to white (no Munsell colour) salts or clays in places, giving a mottled appearance. Excavation into the unit reveals moist, firm, mottled brown (10 YR 5/3 m) and grey (2.5 Y N 5/0 m), laminated clays.

Moderate, vertical, columnar joints occur within the rhythmites, with some extending down through the entire unit. Most of the unit has a blocky fracture with mean block dimensions of about 1 cm by 1 cm.

Interpretation of Unit 7

Sediments of Unit 7 are interpreted to have been deposited in a proglacial lake, indicated by the presence of fine grained rhythmites (cf. Gustavson 1975), and pebbles and lenses of diamicton which deform underlying clay beds and are draped by clay beds and are therefore interpreted to have melted out of floating brash ice. The silt beds were probably deposited by underflows in the lake, and clay and silt rhythmites were deposited distally in the lake (cf. Gustavson 1975). Thinning upward of the silt units indicates a withdrawal of the sediment source, possibly due to retreat of the ice, or enlargement of the lake.

C. Clover Bar

The Clover Bar sections are located on the east side of Edmonton in a gravel pit owned by OK Construction Materials (11-f-53-23-W4), (Fig. 1.1). The sediments described are in section A on the southern pit wall (Fig. 4.6), and section B on the eastern pit wall (4.7). The tops of the sections have an elevation of 658.5 m a.s.l. The distance between the two sections is about 70 m.

1. UNIT 1: CROSSBEDDED SAND AND GRAVEL

Description

At section A, 0.3 m of unit 1 is exposed. the basal 5 m of the section is covered to the pit floor by talus. In other areas of the pit, up to 4 m of the unit is exposed.

The sediments are loose, moist, yellowish brown (10 YR 5/4 m), well-sorted, medium grained sand and some gravel, (USCS classification GP), of dominantly quartzitic composition. Coaly layers occur within the sands. Low to medium angle, planar and trough crossbedding, shows a paleocurrent direction to the east. The upper contact is distinct, wavy and conformable with unit 2.

High angle normal faults are common and show displacements of up to several centimetres.

Interpretation of Unit 1

Unit 1 is interpreted as having been deposited fluvially, indicated by the crossbedding. Lack of Shield

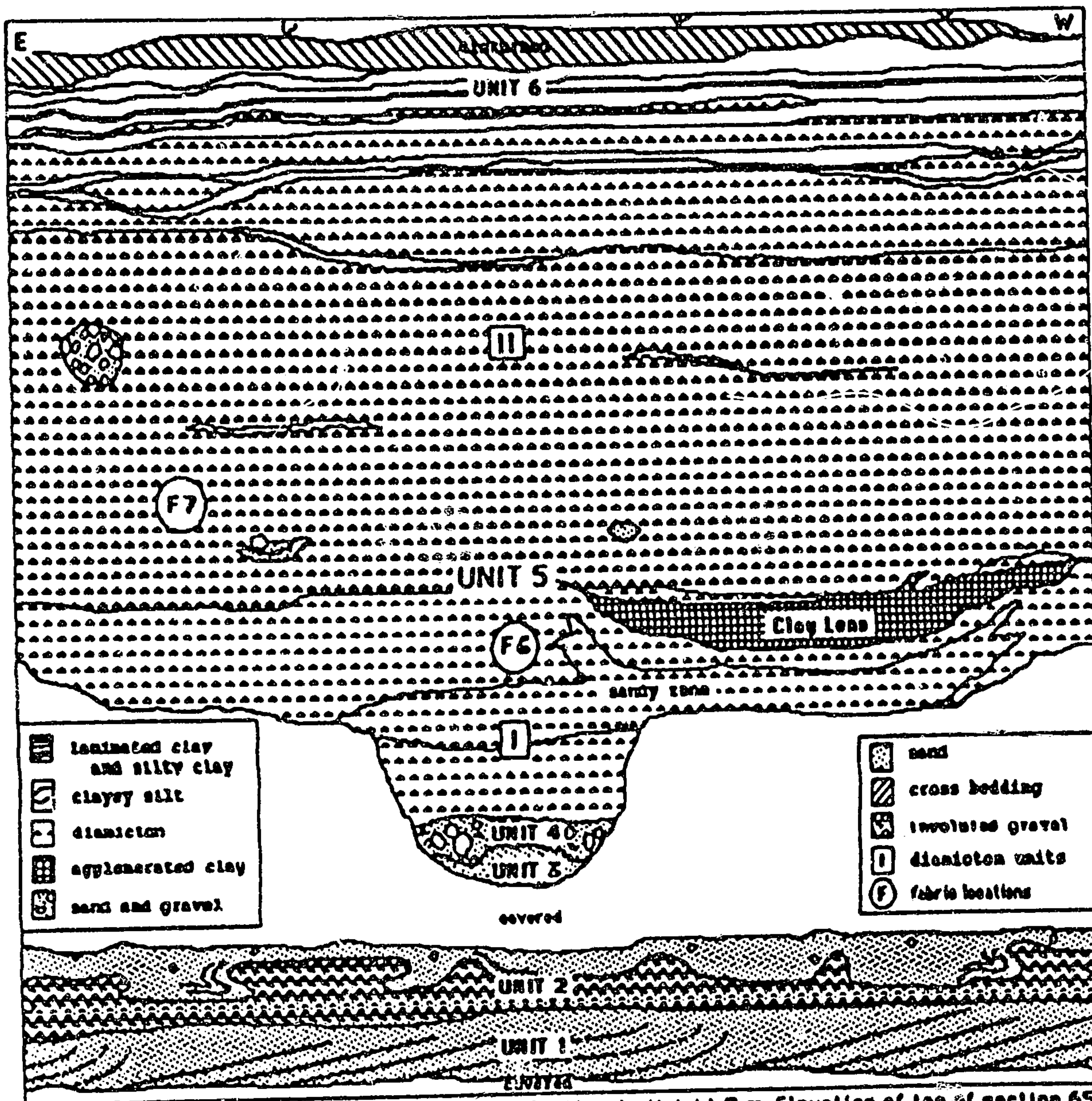


FIG. 4.6. Schematic diagram of Clover Bar Section A. Height 8 m. Elevation of top of section 658.5 m a.s.l.

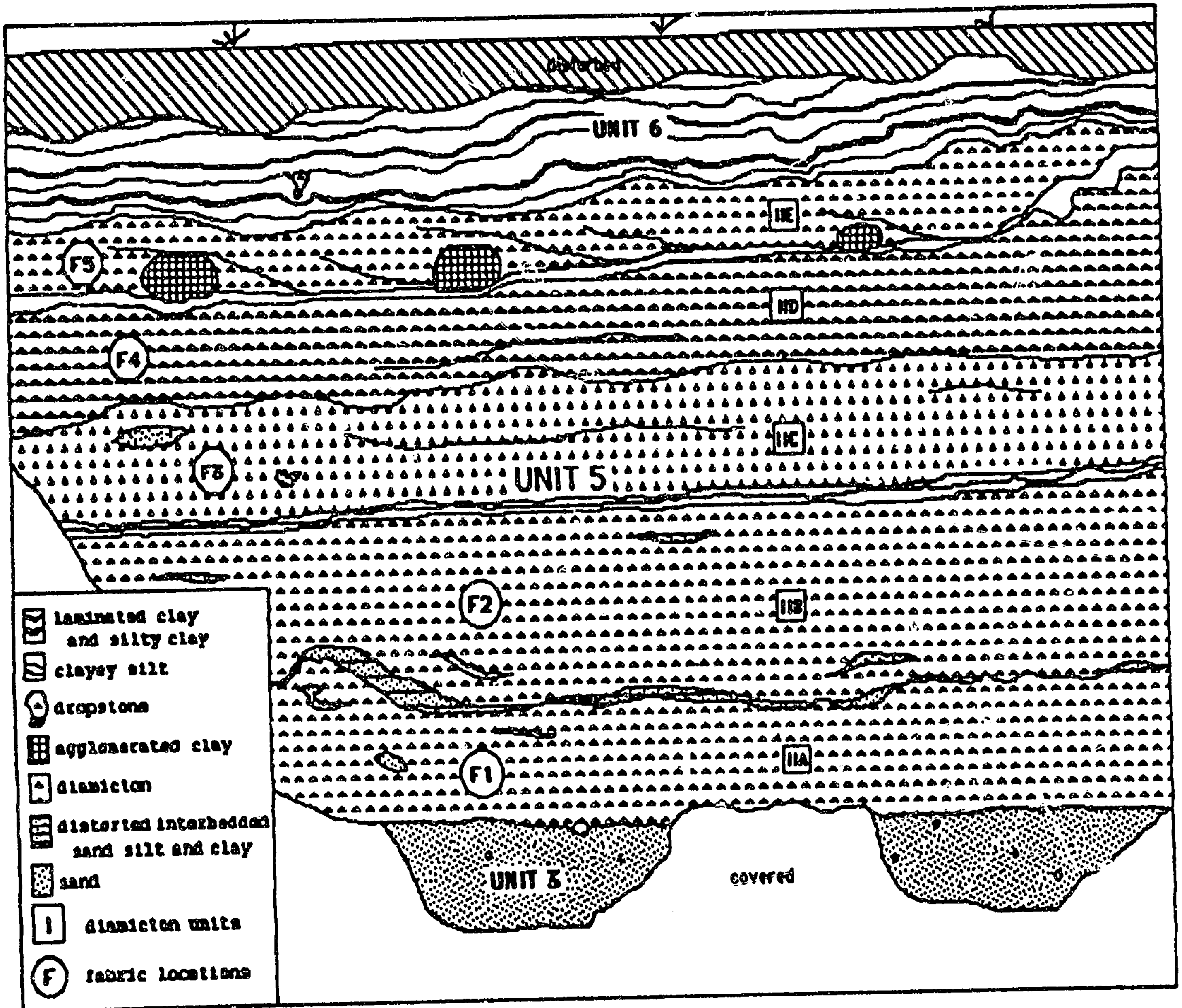


FIG. 4.7. Schematic diagram of Clover Bar Section B. Height 5 m. Elevation of top of section 658.5 m a.s.l.

material indicates it is of preglacial age. Post-depositional faulting is probably the result of periglacial activity in gravel and sand of the overlying unit 2.

2. UNIT 2: GRAVEL AND SAND WITH PERIGLACIAL FEATURES

Description

At Section A, 0.5 m of unit 2 is exposed, with the upper part covered by talus (Fig. 4.6).

Interbedded gravel and sand is overlain by massive sand. The gravel and sand is loose, greyish-brown (10YR 5/2 m), and composed of 53% sand and 47% gravel (USCS classification SP). The clasts are well rounded and predominantly quartzitic. Irregularly-shaped, subrounded intraclasts of diamicton, containing no Shield pebbles, occur within the gravel and sand and are up to about 25 cm in diameter. The upper massive sand contains randomly oriented, isolated, rounded pebbles. Gravel involutions to 0.5 m in height occur in places (Plate 4.4). V-shaped structures infilled with sand and bordered by vertically oriented pebbles are up to 2.5 m in height and 0.75 m in width, and extend down from the top of the gravel and sand. The gravel and sand has a reddish yellow (5YR 6/8 m) oxidation stains and some dark purplish (no Munsell colour) streaks, with staining strongest at the top of the involutions. The sub-planar tops of the involutions and wedges form a horizontal disconformity.

Interpretation of Unit 2

Unit 2 gravel and sand are interpreted to be fluvial

PLATE 4.4. Involuted gravel of unit 2 at Clover Bar. Blue handle of pick is 20 cm long.

sediments which have been disturbed by periglacial processes, because they grade up from crossbedded fluvial sediments but any sedimentary structures have been disturbed by the formation of involutions and wedges caused by periglacial climate conditions. Involutions and V-shaped wedges are interpreted to be formed by frost processes due to the presence of vertically oriented pebbles. The involutions and probable ice wedge casts (cf. Westgate and Bayrock 1964), indicate an active layer formed, probably on a dormant depositional surface such as a river terrace. Later fluvial activity buried the active layer, but frost processes continued to affect the sediments and pebbles were moved upward. Diamicton clasts are probably sediment eroded from streambanks during initial deposition of the sediment. The sediments are preglacial as they lack Shield provenance material.

3. UNIT 3: SAND

Description

Up to 0.5 m of Unit 3 is exposed above covered areas of Section A (Fig. 4.6), and Section B (Fig. 4.7).

Unit 3 is moist, loose, quartzitic, well sorted, medium grained, strong brown (7.5 YR 5/8 m), sand (USCS classification SP), with grey or lighter brown mottling in places. It is massive or crossbedded. Where it is massive, approximately 10 to 15% subrounded to rounded quartzitic pebbles and cobbles up to 10 cm in diameter are dispersed throughout the sand.

Unit 3 is generally overlain by diamicton of unit 5, with a sharp, planar and erosional upper contact, truncating crossbedding. In places the upper contact is distinct and irregular with poorly sorted gravel of unit 4.

Interpretation of Unit 3

Unit 3 is interpreted to be a disturbed fluvial deposit, for crossbedding in places indicates it was originally fluvially deposited, however, the absence of sedimentary structures in places suggests it was affected by periglacial processes. The deposit is preglacial as it lacks material of Shield provenance. The sediments were probably eroded by an overriding ice sheet, suggested by the erosional upper contact with the diamicton complex of unit 5.

4. UNIT 4: SANDY GRAVEL CONTAINING DIAMICTON CLASTS

Description

Unit 4 is discontinuous and variable in thickness, with a mean thickness of 0.1 m.

The lower contact is distinct and irregular with underlying sand of unit 3. The sediments are moist, loose, grey (10 YR 5/1 m), poorly sorted, and predominantly quartzitic gravel, with approximately 80% rounded pebbles, and 20% silt, sand and clay (USCS classification GM). Pebbles are up to 5 cm in diameter. There are some irregularly-shaped diamicton intraclasts several centimetres in diameter, with diffuse boundaries. The upper contact is sub-planar, erosional and sharp with diamicton containing clasts of Shield provenance.

Interpretation of Unit 4

The poorly sorted sediments of unit 4 are interpreted to have been deposited by slumping or debris flow, possibly in a fluvial environment, suggested by the predominance of rounded, gravel-sized clasts. Unit 4 is preglacial, as it does not contain material of Shield provenance. The unit was probably disturbed and eroded by an overriding glacier, suggested by the upper erosional contact with the diamicton complex of unit 5.

5. UNIT 5: DIAMICTON COMPLEX

5a. DIAMICTON I AND CLAY LENS

Description

Diamicton I is discontinuous, and is not present in Section B. In Section A it has a thickness of 1.7 m (Fig. 4.6). To either side of Section A it is covered by talus, however, 25 m to the east where there is no talus, Diamicton I is absent.

The lower contact is sharp and erosional. Diamicton I is slightly moist, stiff, greyish-brown to very dark greyish-brown and matrix-dominated (Table 4.2). The matrix is medium plastic, sandy clay (USCS classification CL), (Fig. 4.8 and Table 4.2), with a lighter coloured sandy zone in the centre of the unit that contains sand stringers and ironstone clasts (Diamicton I middle unit, on Table 4.2). Diamicton I generally plots in the range of debris in transport, and to the right along the T-line, reflecting its finer texture, however, its position farther from the T-line for the lower part of the unit might indicate some deviation from typical englacial debris texture (Fig. 4.9).

	Munsell Colour	W %	PP kPa	Matrix Clay	Matrix Silt	Matrix Sand	% Coarser Than Sand	LL %	PI %	Thickness m	Jointing
Section A											
Diamicton II	pale brown 10 YR 6/3 d to brown 10 YR 5/3m		310 m				6			3.4	moderate blocky weak columnar
Diamicton II u		5.4 w	>480 d	24.0	28.5	47.5	8	27.0	13.0	1.0	
Diamicton II m		8.1 w		23.5	31.0	46.0		24.0	5.5		
Diamicton II l		6.7 w		24.0	30.5	45.5		26.0	14.5		
Diamicton I	grey brown 10 YR 5/2m to very dark grey brown 10 YR 3/2m						5			1.7	
Diamicton I u		14.2	275 m	30.5	28.5	41.0		38.0	23.3		strong rectangular
Diamicton I m		12.9		27.5	26.0	46.5		34.0	20.5		
Diamicton I l		13.6	205 m	31.5	29.5	39.0		39.0	27.5		moderate blocky
Section B											
Diamicton II E	light brown grey 2.5 Y 6/2 d	1.7 w	>480 d	29.0	22.5	48.5	20	31.5	19.0	0.5	moderate subvertical
Diamicton II D	light brown grey 2.5Y 6/2 d	1.6 w	>480 d	23.5	32.0	44.5	8	27.0	13.0	0.8	moderate vertical secondary subhoriz fissures
Diamicton II C	light olive brown 2.5 Y 5/4 d	1.6 w	>480 d l 375 m l	23.5	30.0	46.5	6	26.0	12.0	0.7	moderate vertical secondary blocky
Diamicton II B	grey brown 10 YR 5/2m	3.8 w	>480 m	23.5	31.5	45.0	4	26.5	14.5	0.5	moderate to strong columnar
Diamicton II A	grey brown 10 YR 5/2m	9.2	340 m u 170 m l	24.0	29.0	47.0	5	26.5	12.0	0.6	moderate to strong columnar

TABLE 4.2. Properties of diamictons at Clover Bar. W = water content, PP = pocket penetrometer, LL = liquid limit, PI = plasticity index, kPa = kilopascals, u = upper unit, m = middle unit, l = lower unit, w = weathered. For penetrometer and colour: d = dry, m = moist.

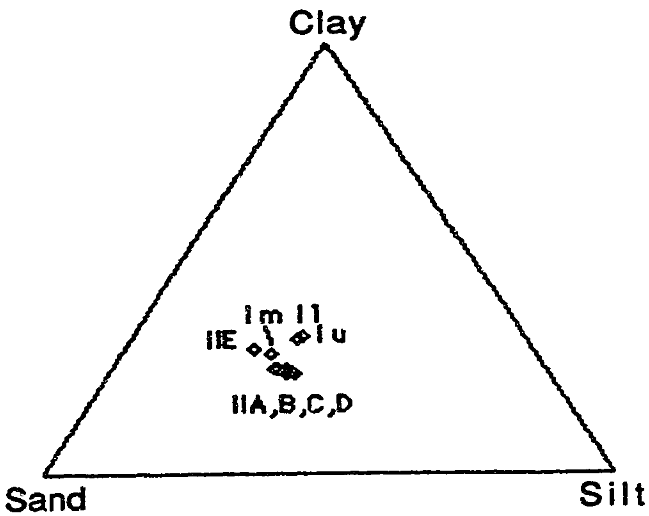


FIG. 4.8. Matrix grain size distributions of diamictons at Clover Bar. Diamictons are numbered I and II. l = lower unit, m = middle unit, u = upper unit.

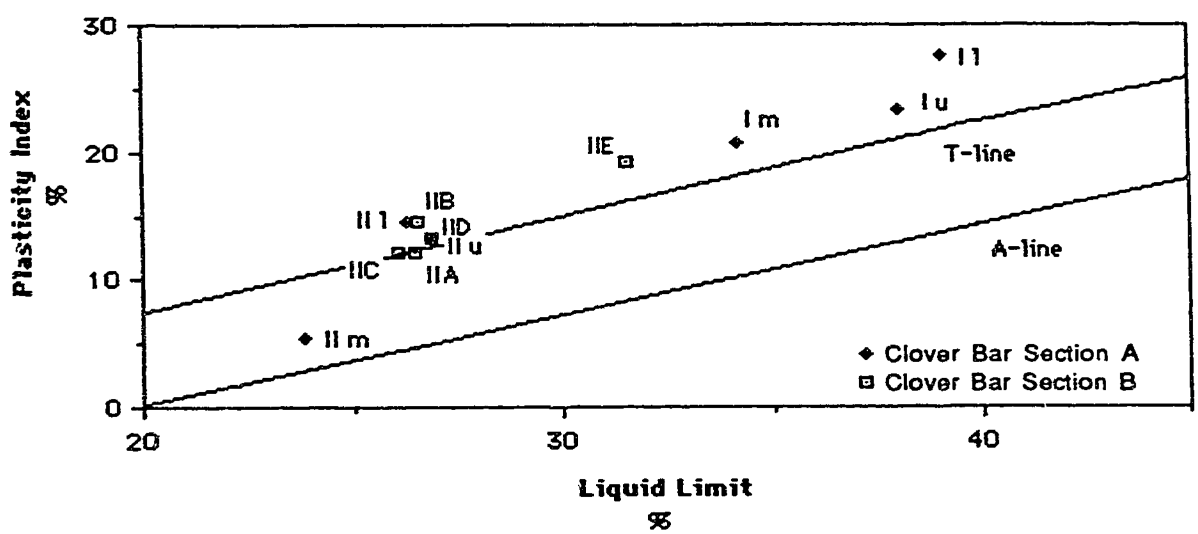


FIG. 4.9. Atterberg limits for diamictons at Clover Bar. u = upper unit, m = middle unit, l = lower unit. Diamictons numbered I and II.

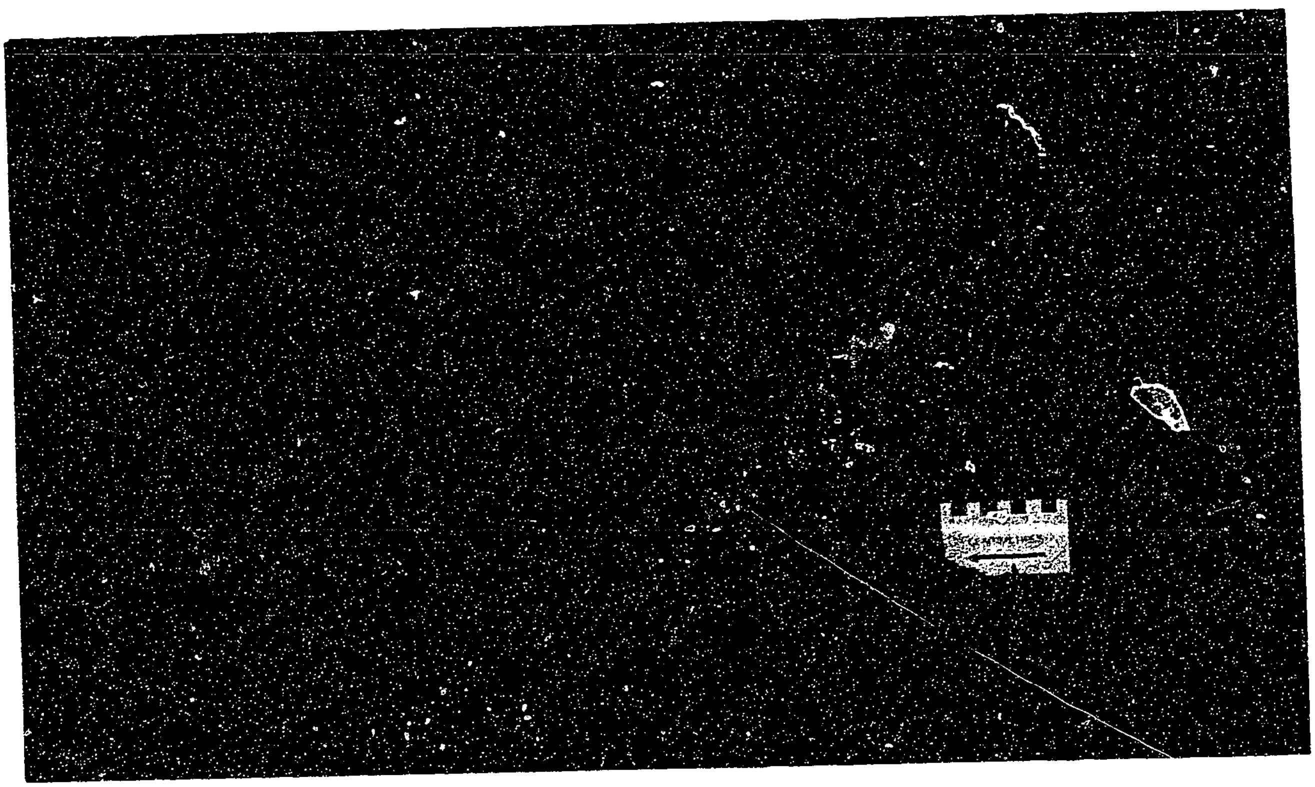
There are approximately 5% subangular to angular pebbles which are up to 3.5 cm in diameter. The predominant clast lithology is quartzite, sandstone and siltstone, with abundant igneous and metamorphic, and some carbonate and coaly shale clasts. Striated clasts are rare.

An elongate clay lens occurs within Diamicton I and along the upper contact of Diamicton I with Diamicton II (Fig. 4.6). It is approximately 5 m in length, with a mean thickness of 28 cm. The lens consists of moist, soft, massive, agglomerated silty clay, which crumbles easily. The sediment is predominantly dark greyish brown (10 YR 4/2 m), mottled brown and grey (no Munsell colour) in places, and consists of 54% clay, 39% silt, and 7% sand, with approximately 2% coarse sand size particles. The liquid limit is 53% and plasticity index is 24%. It has a USCS classification of CH. The upper and lower contacts with diamicton are distinct and undulating. Along the lower contact, small pointed tongues of diamicton extend up into the lens. Where Diamicton II directly overlies the lens, the upper contact of the lens exhibits folding to the west.

The upper contact of Diamicton I with Diamicton II is distinct, irregular to undulating and non-erosional (Plate 4.5). The contact is delineated by an abrupt change in colour and fracture. Small pointed features up to 8 cm in height occur where Diamicton I extends up into Diamicton II.

Three pebble fabrics from the middle and upper part of

PLATE 4.5. Contact between Diamicton I and Diamicton II of the diamicton complex (unit 5) at Clover Bar.



the diamicton have moderate northwest-southeast trend orientations and weaker transverse modes, with moderate plunge angles (Fig. 4.10a).

The diamicton is fractured throughout and breaks into blocks easily. At the bottom, the fractures are moderate to strong, irregular and blocky, grading up into strong, sub-vertical, rectangular fractures. Within the upper 0.25 m, the fracture density is highest and fracture planes are curved (Plate 4.5).

Interpretation of Diamicton I and Clay Lens

Diamicton I is similar to a lower diamicton described by Duff (1951), Westgate (1969), Westgate et al. (1976), and Shaw (1982), with respect to colour, matrix texture composition, fracture and pebble fabric orientation.

The presence of Shield material indicates the sediments are glacial. Diamicton I is interpreted to have been deposited subglacially, indicated by its sharp erosional lower contact and moderately strong fabric. The clayey texture probably reflects incorporated lacustrine sediment, suggested by the presence of the clay lens, which could be a subglacial lacustrine deposit disturbed by overriding ice, as indicated by the presence of fold and load features. The diamicton was probably deposited by melt out where the glacier was separated from its bed (cf. Shaw 1987), and a subglacial pond formed. Sandy zones probably represent debris bands preserved during melt out (cf. Lawson 1981). Formation of the deposit by a possible combination of melt out and glaciolacustrine deposition in

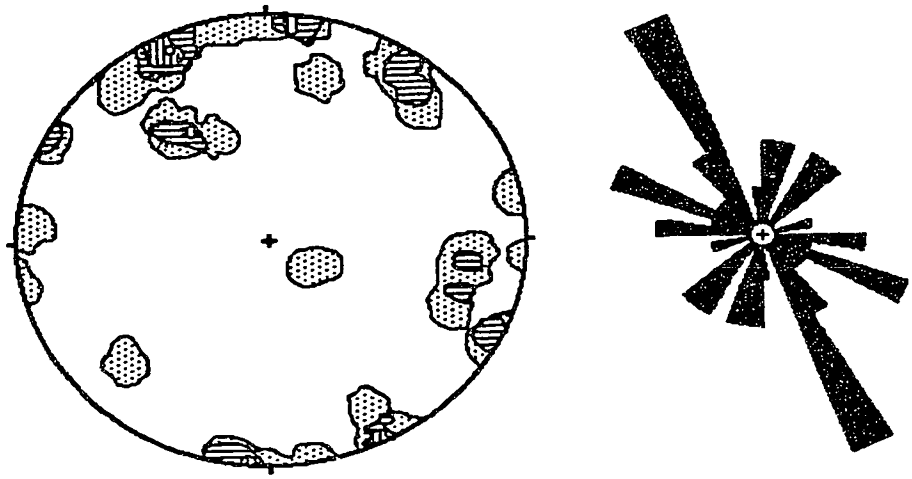


FIG. 4.10a. Diamicton I. N = 25. Mean orientation 335.7. Mean plunge 8.2.° S1 = 0.53, S2 = 0.35, S3 = 0.12.

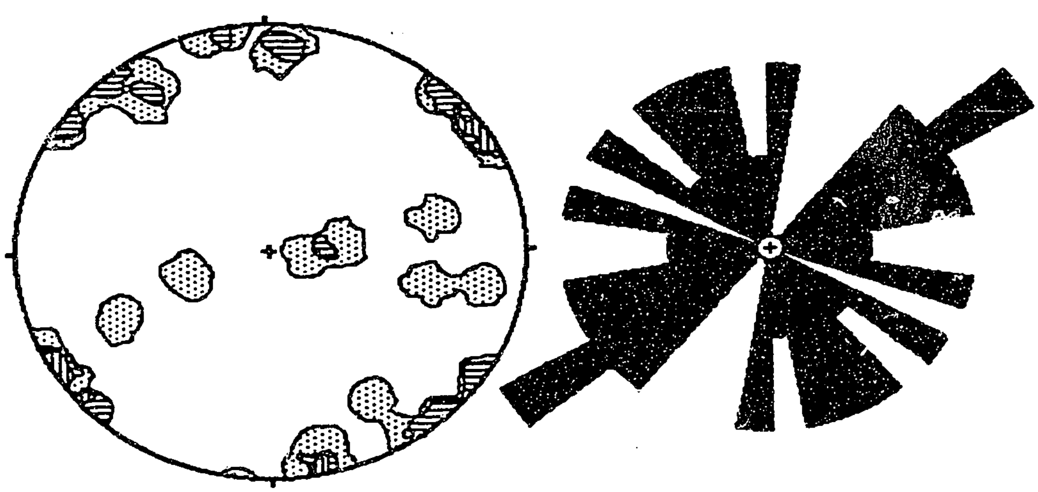


FIG. 4.10b. Diamicton II. N = 25. Mean orientation 147.0. Mean plunge 3.5.° S1 = 0.44, S2 = 0.40, S3 = 0.16.

FIG. 4.10. Pebble fabric contour and rose diagrams for diamictons at Clover Bar. N = number of observations. S1, S2, S3 = eigenvalues. [dotted] 4-7%; [horizontal lines] 8-11%; [vertical lines] 12-15%; [dense vertical lines] 16-19%; [diagonal lines] 20-24%.

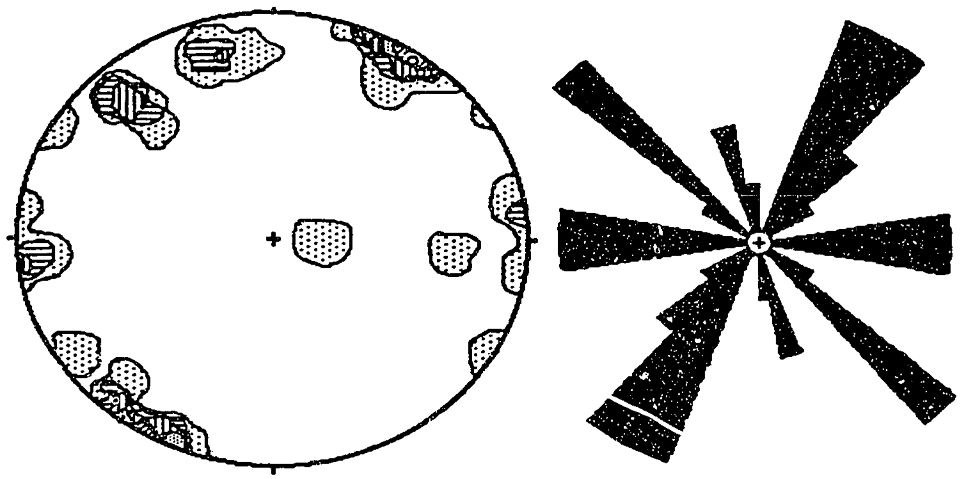


FIG. 4.10c. Diamicton IIA. N = 25. Mean orientation 074.8. Mean plunge 4.7. S1 = 0.54, S2 = 0.38, S3 = 0.08.

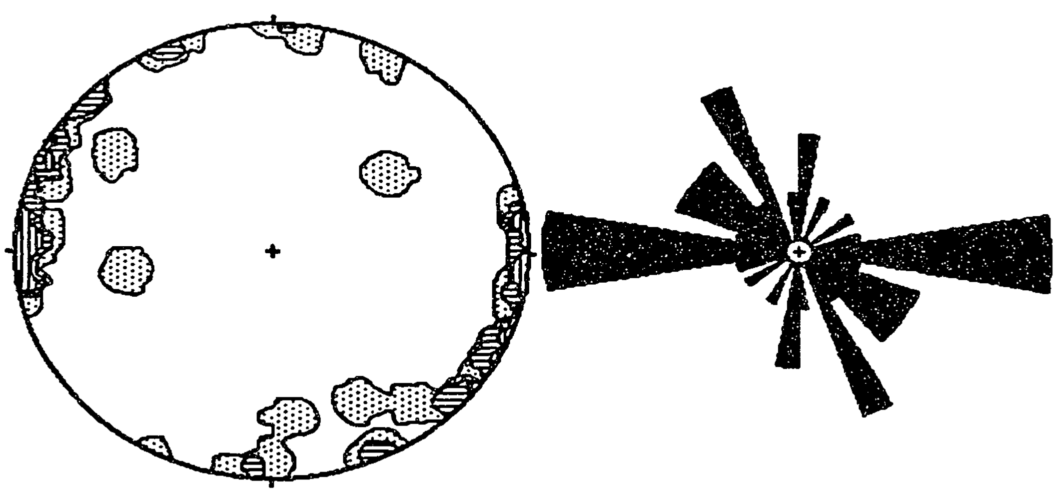


FIG. 4.10d. Diamicton IIB. N = 25. Mean orientation 293.5. Mean plunge 0.9.° S1 = 0.65, S2 = 0.28, S3 = 0.07.

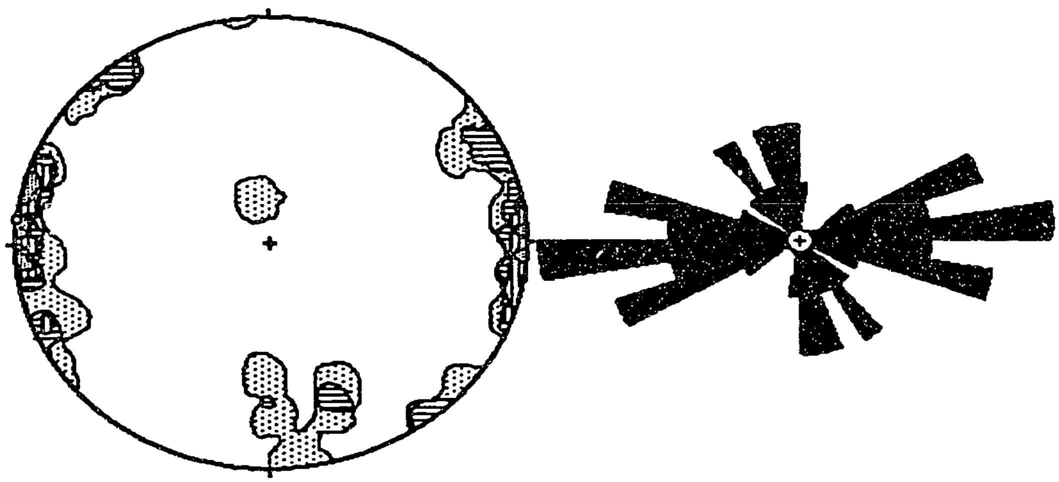


FIG. 4.10e. Diamicton IIC. N = 25. Mean orientation = 276.1. Mean plunge 0.1.° S1 = 0.64, S2 = 0.28, S3 = 0.08.

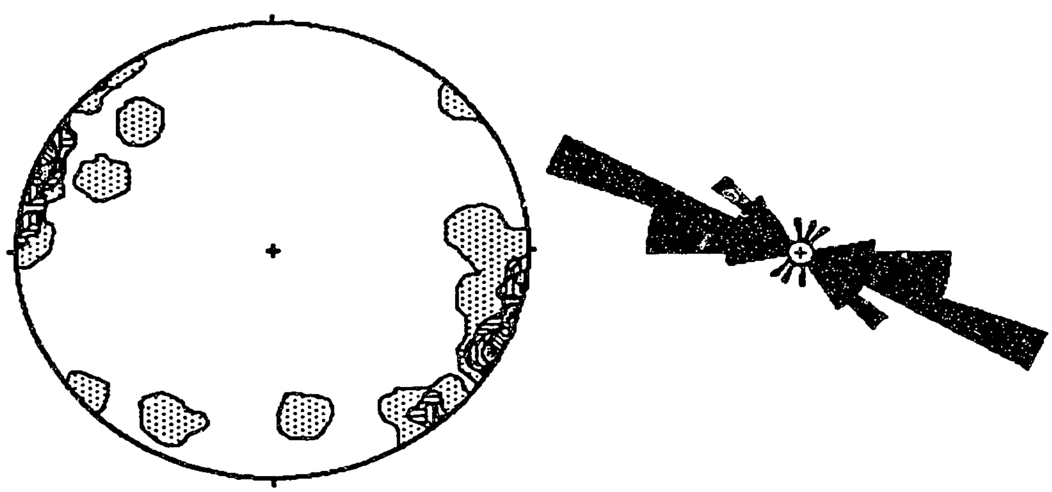


FIG. 4.10f. Diamicton IID. N = 27. Mean orientation = 112.1. Mean plunge 2.0.° S1 = 0.81, S2 = 0.15, S3 = 0.04.

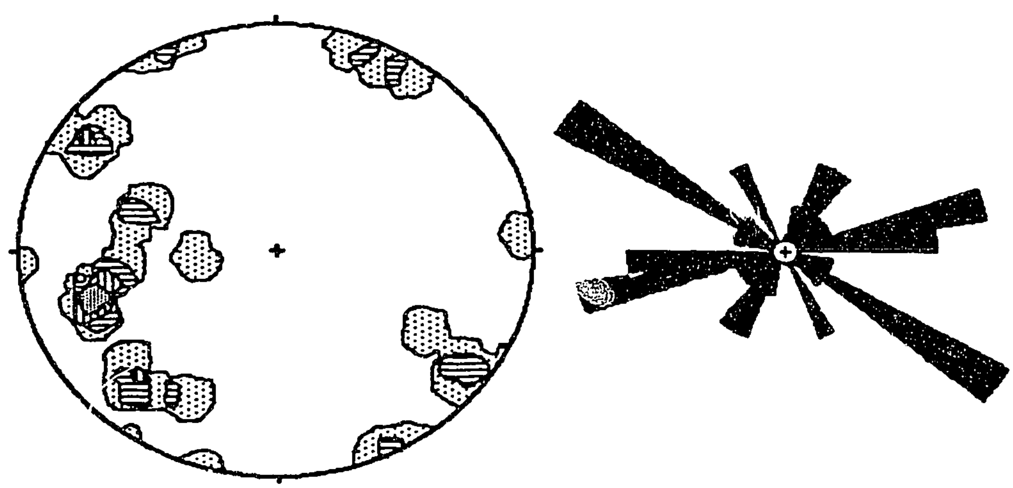


FIG. 4.10g. Diamicton IIE. N = 25. Mean orientation 260.2. Mean plunge 23.4.° S1 = 0.57, S2 = 0.33, S3 = 0.10.

a cavity beneath the ice is supported by moderate strength fabrics, sandy zones, a clay lens and the lateral discontinuity of the unit.

The high fracture density and the distortion of the fractures, the pebble fabric with a transverse component and some high angle plunges, the massive nature of the clay lens and the undulating and sometimes folded upper contact, all suggest that Diamicton I underwent post-depositional disturbance. The irregular contact between Diamicton I and Diamicton II appears to be caused by loading, therefore some of the disturbance of Diamicton I such as intense fracturing, may be due to loading by overlying ice or sediment. Overriding ice may have altered the pebble fabric by weakening it and introducing a transverse northeast-southwest component, as postulated by Westgate and Ramsden (1971), although transverse orientations do develop englacially (Lindsay 1970), and have been postulated for melt-out till (Mark 1974). The non-erosional upper contact, the absence of shear planes, the curved nature of some fracture planes and the load features, suggest that the diamicton was saturated when disturbed by overriding ice, indicating it may have been overlain by water when overridden and underwent viscous flow (cf. MacClintock and Dreimanis 1964). Drainage and consolidation of the unit may also have been inhibited by substrate permafrost conditions in the marginal areas of the ice sheet. Disturbance of Diamicton I may resemble the process which formed ice-pressed features as postulated by

Stalker (1959). Drastic post-depositional disturbance of subglacial lacustrine deposits can be expected because of ice loading (Sugden and John 1976).

The localised distribution of Diamicton I, the non-erosional upper contact, the absence of sorted sediments between Diamicton I and Diamicton II which might represent interstadial sediments and the evidence that Diamicton I remained saturated until after it was overridden, all indicate that Diamicton I was probably not deposited during a separate major glacial advance. The northwest-southeast oriented pebble fabric of Diamicton I may indicate that the melt-out till was deposited by a minor ice lobe from the northwest (cf. Catto 1984), which was probably confined to areas where east-west trending valleys acted to channel ice flow (Catto, personal communication 1989), before the main glacier overrode the area from the northeast. Such an advance, or western, lobe may have been deflected south and east by the regional slope. Shetsen (198[illegible]) determined that the last glacier in southern Alberta was comprised of three lobes, each with individual flow patterns. Diamicton deposited by the earlier lobe may have been overlain by diamicton deposited by another lobe (cf. Eyles et al. 1982).

5b. DIAMICTON II

Description

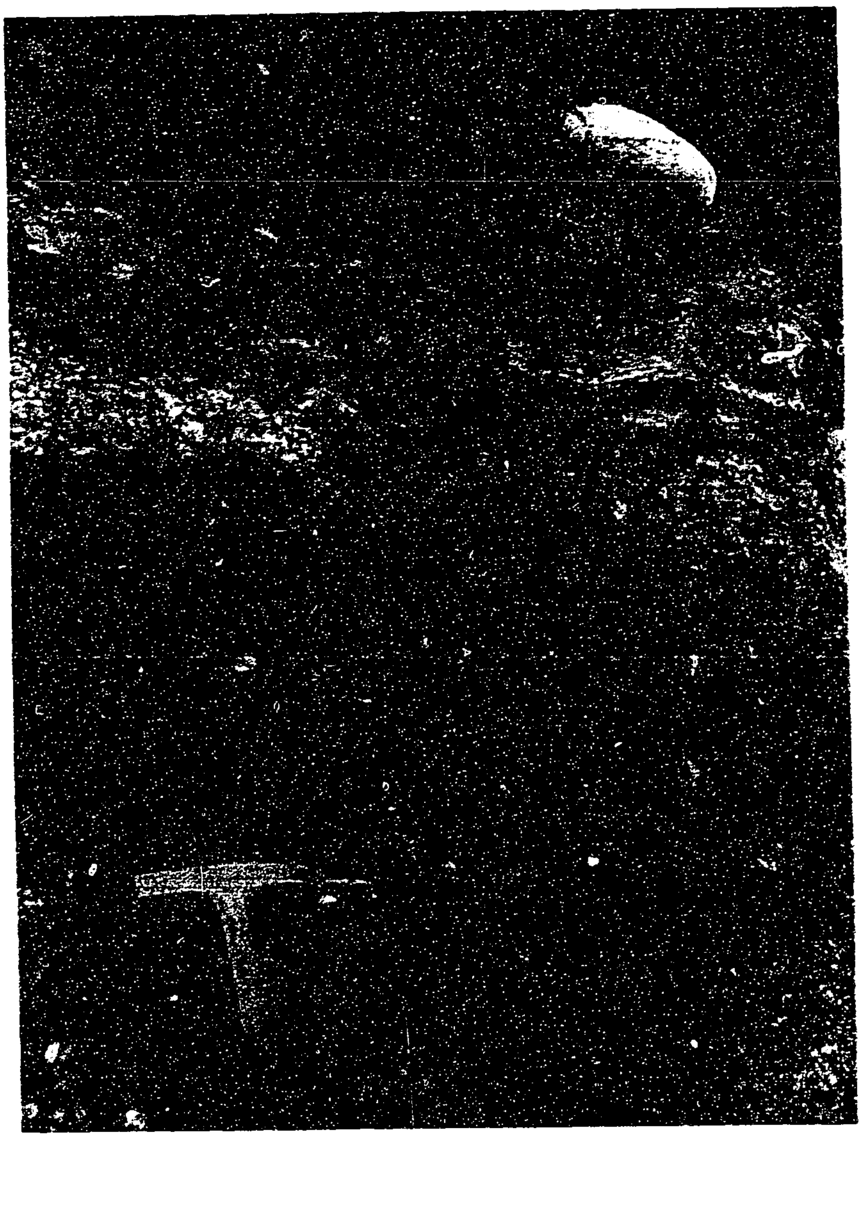
Diamicton II has a mean thickness of 3.4 m.

The lower contact is planar and erosional where it overlies sand of unit 3 (Section B; Fig. 4.7), and irregular and distinct where it overlies Diamicton I (Section A; Fig. 4.6 and Plate 4.5). The diamicton is grey-brown to brown and matrix-dominated, with a low plastic sandy matrix (USCS classification CL), (Table 4.2). It very stiff to hard and grades up from moist to dry (Table 4.2). Diamicton II generally plots to the left along the T-line relative to Diamicton I (Fig. 4.9). The lower sub-units plot close to the T-line in the region of debris in transport, however, the upper sub-units deviate from the T-line, probably reflecting enrichment in sand and clay, respectively.

The mean percentage of clasts is approximately 7% subrounded to subangular pebbles and cobbles up to 12 cm in diameter. The predominant clast lithology is quartzite, sandstone and siltstone, with some igneous, metamorphic, carbonate and coal clasts. Striated clasts are scarce. The lower 10 cm of the diamicton is locally very sandy. Biconvex sand lenses occur in the lower 2 m, are less than 0.25 m wide and 0.15 cm thick, have sharp contacts with surrounding diamicton and contain well-sorted medium grained massive or bedded quartzitic sand. Some iron oxide staining occurs along fractures and around sand pockets. The upper contact of Diamicton II with laminated silty clay of Unit 6 is sharp, conformable and wavy (Plate 4.6).

At Section A (Fig. 4.6), biconvex lenses of massive sand and angular lenses of bedded sand occur in the lower part of the diamicton. Discontinuous stringers of massive silt increase in size and frequency upward, to a maximum of

PLATE 4.6. Upper part of the diamicton complex (unit 5) at Clover Bar, showing Diamicton II and overlying laminated clay and silty clay (unit 6) containing a diamicton lens with large clasts. Hammer head is 20 cm long.



1.5 m in length and 1 cm in thickness. Sand wisps occur throughout the unit. An elliptical pod of clast-dominated diamicton approximately 15 cm in diameter with distinct contacts with surrounding matrix-dominated diamicton occurs in the upper part of the unit. The uppermost approximately 1 m is composed of diamicton lenses interbedded with laminated silty clay layers to several centimetres thick. The diamicton has moderate, blocky fracture that weakens upward and weak to moderate, random, columnar jointing with a mean spacing of about 0.3 m.

At Section B (Fig. 4.7), five diamicton beds separated by sorted sediments can be distinguished. All the diamictons extend laterally for tens of metres, generally thickening to the south on the section face.

Diamicton IIA contains sand and gravel lenses to 20 cm in length with distinct biconvex contacts. The dominant clast lithologies are quartzite, ironstone and coal. Diamicton IIA grades up into discontinuous, undulating and distorted interbedded sand, silt and clay, up to 30 cm in thickness.

The sand grades up into Diamicton IIB, which contains wavy sand stringers up to 1 cm in thickness, concentrated within 5 cm of the upper contact. The dominant clast lithology is quartzite, with some shale, carbonate, coal and highly weathered schist. Moderate to strong columnar jointing extends through Diamictons IIA and IIB, with approximately northeast-southwest and northwest-southeast orientations, and a spacing of 5 to 10 cm. Although some joints extent up into overlying diamicton, the jointing pattern is stronger and more closely spaced in the lower two diamictons. Iron oxidation staining is concentrated along joints. The upper contact of Diamicton IIB is sharp but conformable with ungraded laminated silty clay beds with a mean thickness of 8 cm and dipping approximately 2 degrees northward. The beds consist of stiff, dry, light and dark laminae (olive yellow, 2.5 Y 6/6 m; greyish-brown, 10 YR 5/2 m), with a mean composition of 42% clay, 30% silt and 28% sand, moderately high plasticity (LL 43.5, PI 30.7), and disturbed and wavy bedding in places.

The silty clay grades up into Diamicton IIC, which is moist at the base, becoming drier upwards. Sand lenses up to 15 cm in length are biconvex or irregular in shape and consist of massive medium grained quartzitic sand. Silt stringers less than 1 cm thick and up to 1 m in length are undulatory and occur throughout the unit. The dominant clast lithology is quartzite, ironstone, granite, coal, sandstone and some highly weathered schists. The upper contact with massive silty clay is wavy and sharp. The silty clay is dark grey (10 YR 4/1 m), and varies from 0.25 to 2 cm in thickness.

The silty clay grades up into Diamicton IID. Diamicton IID contains some silt stringers, and has a clast lithology dominated by oxidised sandstone, quartzite, carbonate, granite, schist and some coal. The upper contact with silty clay is wavy and sharp. The light grey (10 YR 7/2 d) ungraded laminated clay with wavy bedding is approximately

2 cm thick, and has strong blocky fracture. It is disturbed or partially eroded beneath large clay balls which occur at the base of Diamicton IIE.

The silty clay grades up into Diamicton IIE. Diamicton IIE is more variable in thickness than the underlying diamictons (Fig. 4.7). Also, the matrix has a different textural distribution, having higher clay and sand fractions and a lower silt fraction, and a much higher pebble and cobble content (Table 4.2). Reverse grading of the matrix occurs in the lowermost 10 cm, with normal grading above. Cobbles are distributed throughout, with a weak reverse grading and a concentration near the top of the unit. The clast lithology is dominantly quartzite, granite, carbonate and ironstone, with rare coal. Silt streaks about 0.5 cm thick and up to approximately 30 cm in length extend upward from the underlying silty clay into the diamicton, dipping at angles of 5 to 10 degrees to the south and extending halfway through the unit. They are wavy and curve over agglomerated clay balls located sporadically along the base of the unit. The clay balls are ellipsoidal pockets of dry, soft to firm, agglomerated, sandy, silty clay (40% clay, 31% silt, 29% sand; USCS classification CL), up to 10 cm thick, and 16 cm long and wide. The contact with surrounding diamicton is sharp.

Jointing within the upper three diamictons is moderate columnar, weakening upward and irregularly spaced, with a secondary, weak, blocky fracture in places. Orientations of column faces are approximately northwest-southeast and transverse in Diamicton IIC, and north-south and transverse in Diamicton IID.

Pebble fabrics from the lower part of Diamicton II at Section A, and from Diamicton IIA at Section B , have weak to moderate northeast-southwest and weak transverse trend orientations, with high scatter and a wide range of plunge angles (Figs. 4.10b, and c). Diamictons IIB, IIC, IID and IIE at Section B have moderate to strong, unimodal pebble fabrics with approximately east-west trend orientations (Figs. 4.10d,e,f,g).

Interpretation of Diamicton II

The lower part of Diamicton II is interpreted to have been deposited subglacially, indicated by the sharp erosional lower contact where it overlies sand or gravel of unit 3, and the moderate northeast-southwest pebble fabric parallel to known ice movement direction. The process of deposition was probably melt out, indicated by the low plunge angles of the pebbles (cf. Lawson 1979), and the presence of biconvex sand lenses, draped sand lenses and angular sand lenses which were probably frozen when incorporated and could not have survived deposition by lodgement (cf. Shaw 1982).

The majority of Diamicton II is interpreted to have been deposited by debris flows, indicated by fabrics that have girdles (cf. Rappol 1985), or are unimodal but not parallel or transverse to known direction of regional ice movement (cf. Lawson 1979), and the lensoid or tabular geometry of individual units that are separated by laminated silty clay, suggesting the flows were subaqueous. Ungraded laminated silty clays were probably deposited by suspension settling in a proglacial lake (cf. Gustavson 1975). Pods of very poorly sorted gravel were probably frozen and rolled during flow, giving them an elliptical shape. Sorting processes probably resulted in coarser textures than Diamicton I. The massive and thicker lower flow units are similar to non-channelised Type I sediment flows as classified by Lawson (1982). The uppermost Diamicton IIE was deposited by a debris flow which ripped up underlying lacustrine sediments and sheared them, forming silt streaks, and rolled them, forming clay balls. The higher pebble and cobble content of Diamicton IIE may indicate that the debris source was partially sorted, coarse grained material, and was not transported far. The flow was probably laminar, allowing clasts to be suspended within the sediment (cf. Lawson 1982). Diamicton IIE resembles more fluid lobate to channelised sediment flows of Type II or III as classified by Lawson (1982).

Columnar jointing in Diamicton II is probably due partly to dessication (cf. Soderman and Kim 1970) and partly to stress release on the section face (cf. Matheson and Thomson 1973, Babcock 1974, Catto 1984), because joint orientations seem to be influenced by both the macrofabric of the diamicton and the orientation of the outcrop face. The formation of the columnar joints is selective to Diamicton II, possibly because of its upper stratigraphic position where it is more susceptible to dessication. The lighter colour of Diamicton II relative to Diamicton I is due to oxidation and possibly a lower clay content.

6. UNIT 6: INTERBEDDED CLAY AND SILTY CLAY

Description

Unit 6 has a mean thickness of 0.5 m. Although it varies in thickness laterally, with undulatory lower and upper contacts, it is continuous and blankets the diamicton deposits.

The unit consists of dry to slightly moist, firm to stiff, laminated, olive grey (5 Y 4/2 m) and light grey (10 YR 7/2 d), silty clay and clay. In the lower part of the unit, light grey, ungraded silty layers are composed of 63% clay, 28% silt, and 9% sand with a liquid limit of 50% and plasticity index of 31%, and dark grey clay layers are composed of 89% clay, 9% silt, and 2% sand with a liquid limit of 78% and plasticity index of 49%. The USCS classification is CH. Laminae show lateral variations in thickness, and thin and become more clayey upward. Subangular to subrounded, very coarse sand or pebbles to 2.5 cm in diameter truncate bedding and distort underlying beds. Diamicton lenses occur in places (Plate 4.6). The clay has a strong, blocky fracture. Locally disturbance has caused the bedding to undulate or be difficult to distinguish. In the upper part of the unit pedological processes obscure laminae. The upper contact with disturbed material is distinct and undulatory.

Interpretation of Unit 6

The laminated clays are interpreted to have been deposited in a proglacial lake, indicated by the presence of rhythmites (cf. Gustavson 1975), and pebbles which deform underlying clay beds and are interpreted to have melted out of floating brash ice. Thinner rhythmites in the upper part of the unit were formed as sediment supply diminished as the ice retreated or the lake deepened and enlarged. Disturbance of the bedding may have been caused by lake currents or periodic exposure at a marginal lake position. Rapid drainage of the lake, as indicated by high discharge outlet channels such as the Gwynne Outlet (Hughes 1958), probably also caused sediment disturbance.

7. UNIT 7: DISTURBED SEDIMENT

Unit 7 is a discontinuous layer of loose, loamy, structureless sediment, with a mean thickness of 0.3 m. The material is probably the result of bulldozing.

D. Correlation of Big Bend and Clover Bar Sections

The stratigraphy of Quaternary sediments in Edmonton is summarised in Fig. 4.11.

Fluvial sediments overlying Upper Cretaceous bedrock and not containing material of Shield provenance are grouped into the Preglacial Fluvial Unit, represented by Big Bend unit 2 and Clover Bar units 1 to 4.

Discontinuous fluvial sediments, containing diamicton lenses and material of Shield provenance, are grouped into the Proglacial and Subglacial Fluvial Unit, represented by Big Bend units 3 and 4 and absent at Clover Bar.

Till 1 is a post-depositionally disturbed diamicton

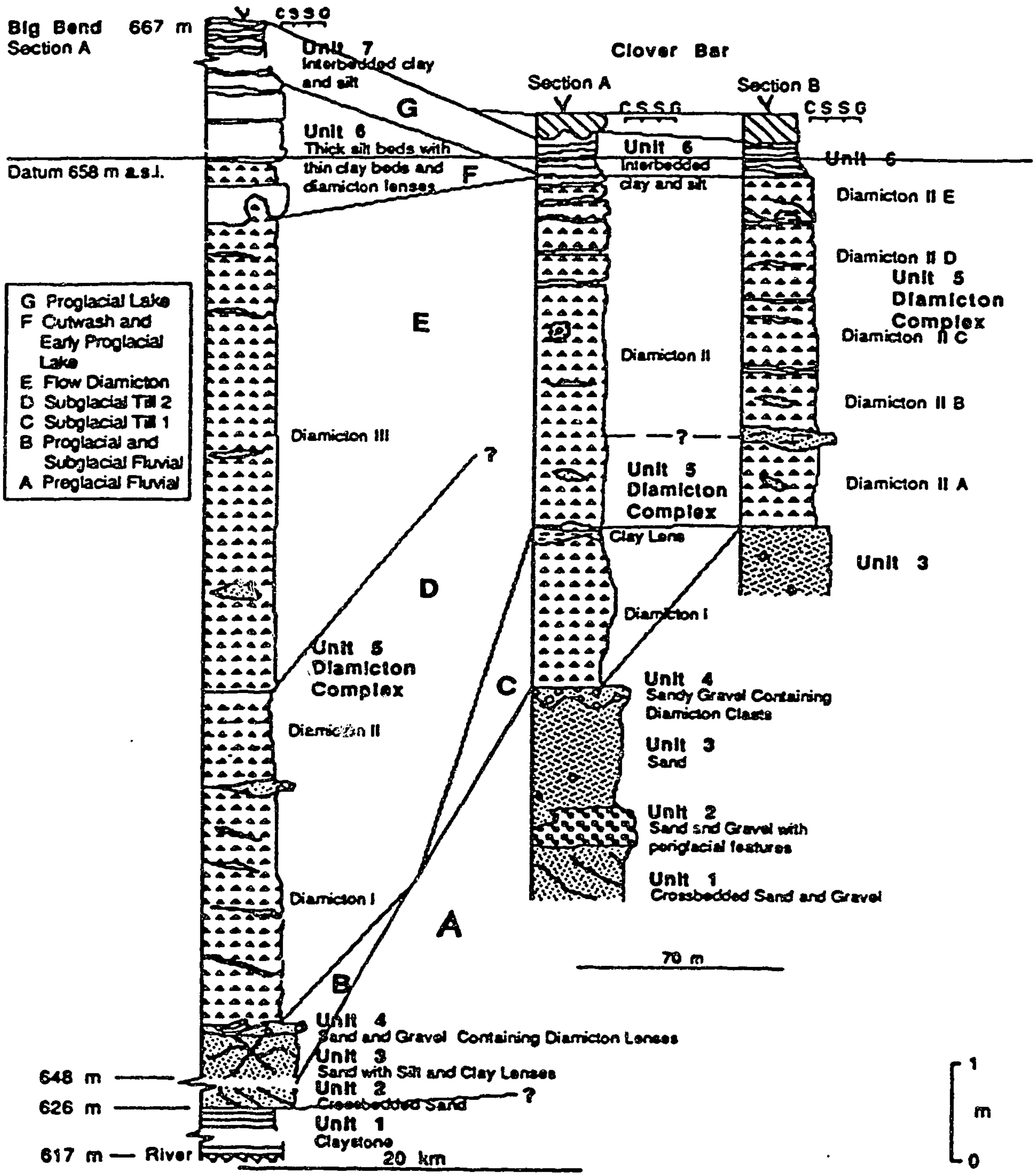


FIG. 4.11. Stratigraphic columns and correlation between Big Bend and Clover Bar.

deposited subglacially, probably by melt out in pockets beneath an advance lobe of ice moving from the northwest. It has a patchy distribution and occurs as the lowermost component of a diamicton complex. It is absent at Big Bend and is represented by Clover Bar Diamicton I of unit 5.

Till 2 was deposited subglacially, probably predominantly by melt out with a lodgement component at the base, by ice advancing from the northeast which disturbed underlying Till 1, and has a widespread distribution. It is represented by Big Bend Diamictons I and II of unit 5 and possibly by the lower part of Clover Bar Diamicton II of unit 5 (Diamicton IIA).

The tills are differentiated by colour, pebble fabric, stratigraphic position, fracture, moisture, Atterberg limits and the presence of a clay lens. The textures alone are not distinctive enough to distinguish the tills, because each till contains a variety of matrix textures.

Sediments of the Flow and Resedimented Diamicton Unit were deposited by debris flow and affected by diapir formation in a proglacial environment. The unit constitutes the upper part of the diamicton complex. Some of the upper flows were probably deposited subaqueously in a proglacial lake, and the diamicton was saturated when it underwent diapir formation, therefore the unit grades upward into the Outwash and Early Proglacial Lake Unit. It is represented by Big Bend Diamictons III and IV of unit 5 and by Clover Bar Diamictons IIB, IIC, IID, and IIE of unit 5.

The flow diamicton is differentiated from the tills by pebble fabric, sedimentary association, stratigraphic position and the content of coarse sediment. Flow diamicton generally has higher percentages of sediment coarser than sand size, however, textures and Atterberg limits are variable and not distinctive. Diapiric diamicton is distinguishable by its geometry and by its texture which is enriched in silt.

Interbedded thick silt beds, thin silty clay layers, and flow diamicton are grouped into the Outwash and Early Proglacial Lake Unit. This unit is represented by Big Bend unit 6 and is absent at Clover Bar.

Rhythmically bedded clay and silty clay laminae form the Proglacial Lake Unit. The clays are represented by Big Bend unit 7 and by Clover Bar unit 6.

E. Summary of the Glacial History

Little glaciofluvial sediment was deposited over Upper Cretaceous bedrock or preglacial fluvial sediments during glacial advance in the Edmonton area, or it was eroded by the overriding ice.

A single glacigenic diamicton complex in Edmonton is composed of two subglacial tills and flow diamicton, all of which vary in thickness and distribution. If Till 1 was deposited during an earlier glaciation, most of the unit and any interstadial sediments were eroded before deposition of Till 2, or earlier deposits may only have been selectively preserved in some deep buried bedrock channels (Andriashek 1988). A more probable explanation is that Tills 1 and 2 in Edmonton were deposited by the same glacier. There may have been two separate ice lobes or advances of the last glacier (Catto 1984), with an indeterminate time period between deposition of the tills, but with permafrost conditions existing between advances as postulated by Shaw (1982). The evidence for plastic disturbance of Till 1 and the non-erosional upper contact with Till 2 suggest that Till 1 was overridden and disturbed while saturated, possibly because it was deposited in a subglacial pond, drainage of the deposit was inhibited due to permafrost conditions, or it was overlain by a lake when overridden.

As the ice retreated, diamicton debris flows were deposited ice-proximally, and into a proglacial lake which formed. Meltwater from beneath the retreating ice deposited sand and silt beds by undercurrent flow, laminated clays were deposited by suspension settling in the lake, and flow diamicton beds were interbedded with outwash sediments. As the ice melted and retreated the sediment supply diminished and the lakes were dominated by rhythmic gravity flow and settling sedimentation. Diamicton lenses were deposited by melting out from floating ice pieces. The lakes drained rapidly, causing disturbance of bedding in the fine grained lake sediments.

CHAPTER V
BOREHOLE STUDY

A. Introduction

612 drill logs from central Edmonton were used in the study. The borehole coordinates are located using a UTM cadastral grid (Fig. 5.1, in pocket). The boreholes penetrate preglacial and glacial Quaternary sediments, as well as Upper Cretaceous bedrock, which was recorded on 238 of the logs. A list of the boreholes and reference sources is presented in Appendix B. Concentrations of boreholes occur in areas of high building density such as downtown Edmonton and the University of Alberta. They are also closely spaced along the Light Rapid Transit (LRT) tunnel route, which extends from the northeast of the map area to the southwest across downtown Edmonton, south across the North Saskatchewan River and southwest across the university.

The modern North Saskatchewan River valley is incised into bedrock and bisects the study area from west to east. The uppermost river terrace at approximately 655 m elevation was used as an arbitrary datum below which boreholes were considered to be located within the valley. Sediments within the valley are considered as a single unit (Valley Sediments) that has undergone an indeterminate amount of erosion and mass movement during Holocene time. Since only 23 boreholes are located within the valley, sediments are not described or mapped but are shown in cross sections and briefly discussed. A total of 589 drill logs were thus used to construct isopach and contour maps of sediment units north and south of the river valley.

B. Sediment Units

Sediment overlying bedrock outside of the North Saskatchewan River valley has a mean thickness, in the boreholes of this study, of 21.3 m, with a standard deviation of 8.2 m, a minimum of 6.6 m (hole 310), and a maximum of 45.8 m (holes 249 and 253). Upper Cretaceous bedrock is not exposed outside of the valley. There are eight major sediment units with bedrock as the lowermost unit and anthropogenic fill as the uppermost unit.

Mean unit properties are rounded to the nearest 0.5, except for density and consolidation coefficient. All of the data is derived from logs except for results from tests done for this thesis in the Quaternary laboratory on samples obtained from Thurber Consultants Ltd. from boreholes 580, 582, 601, and 602, which were analysed for grain size, Atterberg limits and lithology.

1. UNIT 1: BEDROCK

Description

The uppermost bedrock in the study area is considered to be sediment of the Upper Cretaceous Horseshoe Canyon Formation, as mapped by Green (1972). Claystone (including shale and mudstone) is the sediment type at the top of bedrock in 85% of the boreholes which reach the unit. Most of the boreholes which reach bedrock are located over bedrock highs and penetrate approximately a metre of the unit. Claystone, siltstone and sandstone are commonly interbedded, and bentonite and coal seams occur in places. Unified Soil Classification System (USCS) classifications are CH, CI, and SC. Bedrock colour is described as dark to light grey, grey-green, blue-grey or brown-grey. The contact of bedrock with sand of unit 2, diamicton of unit 3 or sand of unit 4, is abrupt and unconformable. Deep bedrock lows are overlain by continuous deposits of sand of unit 2, and highs are overlain by sand of unit 2, diamicton of unit 3 or sand of unit 4.

The claystone is generally moist and hard (Table 5.1a). Sandstone has lower water contents and higher blow counts than claystone (Table 5.1a). The water table is commonly either several metres above the bedrock surface or within bedrock. The top of bedrock, to approximately 0.5 m depth, is soft or highly fractured in places. Blow counts from the upper surface of bedrock are lower than the average for the unit. Rubbly bedrock or clast dominated diamicton occurs at the top of bedrock on bedrock highs. Bentonite beds are of high plasticity with liquid limits up to 140%, plasticity indices up to 95%, and blow counts lower than claystone.

Bedrock Topography

Bedrock highs occur in the east and south of the map area, with steep slopes down to a low in the west and northwest (Fig. 5.2). The slope to the northwest is the eastern valley wall of the buried preglacial Stony Valley

TABLE 5.1a. Average properties of borehole sediment units. kPa = kilopascals. # = number of datapoints. SD = standard deviation.

Unit	Water Content (%)	Blow Counts per 0.3 m (N)	Pocket Penetrometer (kpa)	Unconfined Compressive Strength (kPa)
7 SAND (MEAN)	15.0	15.0	---	---
(SD)	7.5	4.5	---	---
(#)	4	3	---	---
6 CLAY	29.5	17.0	186.5	183.0
	5.0	8.5	77.5	74.5
	384	349	129	147.0
6A DIAMICTON interbedded with clay and silt	20.0	44	261.0	189.0
	5.5	36.5	122.0	69.0
	84	75	19	14
5 SILT	22.5	33.5	246.5	110.5
	6.0	17.5	169.5	28.5
	165	144	7	16
4 SAND	10.0	41.0	285.0	86.0
	5.5	23.0	164.5	41.0
	244	250	6	3
4C DIAMICTON lenses or beds in sand	17.5	77.5	361.5	178.5
	3.5	51.0	98.0	---
	43	42	9	5
3 DIAMICTON COMPLEX	15.5	83.0	359.0	423.0
	4.0	65.5	95.0	209.0
	895	1180	84	82
3A SAND LENSES in DIAMICTON	16.5	90.0	---	509.0
	4.0	32.0	---	---
	22	23	---	1
2 SAND	9.5	117.0	275.0	---
	4.0	41.5	193.5	---
	87	98	3	---
1 CLAYSTONE	22.0	86.0	393.0	578.0
	7.0	38.0	108.0	268.0
	100	100	16	12
SANDSTONE	19.5	118.0	---	---
	4.0	53.0	---	---
	10	14	---	---

TABLE 5.1b. Average properties of borehole sediment units. LL = liquid limit, PL= plastic limit, PI = plasticity index. # = number of datapoints. SD = standard deviation.

Unit	Atterberg Limits LL (%)	PL	PI	Grain Size Clay (%)	Silt	Sand	Gravel	Dry Density (g/m3)	Wet	Consolidation Coefficient (Cc)
7 SAND	---	---	---	---	---	---	---	---	---	---
6 CLAY (MN)	55.5	24.5	31.0	48.5	44.0	8.0	---	1.4	1.9	0.27
(SD)	12	4	9.5	15.0	16.0	8.0	---	0.1	0.03	0.1
(#)	178	178	178	11	11	11	---	20	6	20
6A DIAMICTON interbedded with clay and silt	33.5	16.0	17.0	18.0	58.0	24.0	---	1.3	2.1	0.2
	4.0	3.5	6.5	---	---	---	---	---	0	---
	5	5	5	1	1	1	---	1	2	1
5 SILT	34.5	22.0	12.5	14.0	79.0	7.0	---	1.6	1.8	0.14
	9.0	4.0	8.0	4.5	8.5	7.5	---	0.2	---	0.04
	16	16	16	4	4	4	---	4	1	2
4 SAND	---	---	---	5.0	21.5	73.0	---	---	---	---
	---	---	---	[illegible]	16.5	17.5	---	---	---	---
	---	---	---	[illegible]	8	8	---	---	---	---
4C DIAMICTON lenses or beds in sand	35.0	18.0	17.0	19.5	40.5	40.0	---	---	---	---
	2.5	3.0	3.5	0.5	0.5	---	---	---	---	---
	5	5	5	2	2	2	---	---	---	---
3 DIAMICTON COMPLEX	36.0	16.5	19.0	19.5	42.0	38.5	---	1.9	2.2	0.1
	8.5	3.0	8.0	10.5	11.0	13.0	---	0.1	0.05	---
	80	80	80	32	32	32	---	4	8	1
3A SAND LENSES IN DIAMICTON	---	---	---	4.0	36.0	60.0	---	---	---	---
	---	---	---	---	---	---	---	---	---	---
	---	---	---	1	1	1	---	---	---	---
2 SAND	---	---	---	---	7.0	75.0	18.0	---	---	---
	---	---	---	---	4.5	21.5	19.5	---	---	---
	---	---	---	---	5	5	5	---	---	---
1 CLAYSTONE	6.0	26.5	39.5	39.0	45.5	15.5	---	1.7	1.7	---
	27.5	7.0	21.0	---	---	---	---	0.01	0.5	---
	10	10	10	1	1	1	---	3	3	---
SANDSTONE	---	---	---	---	52.0	39.5	8.5	---	---	---
	---	---	---	---	1.0	7.5	6.5	---	---	---
	---	---	---	---	2	2	2	---	---	---

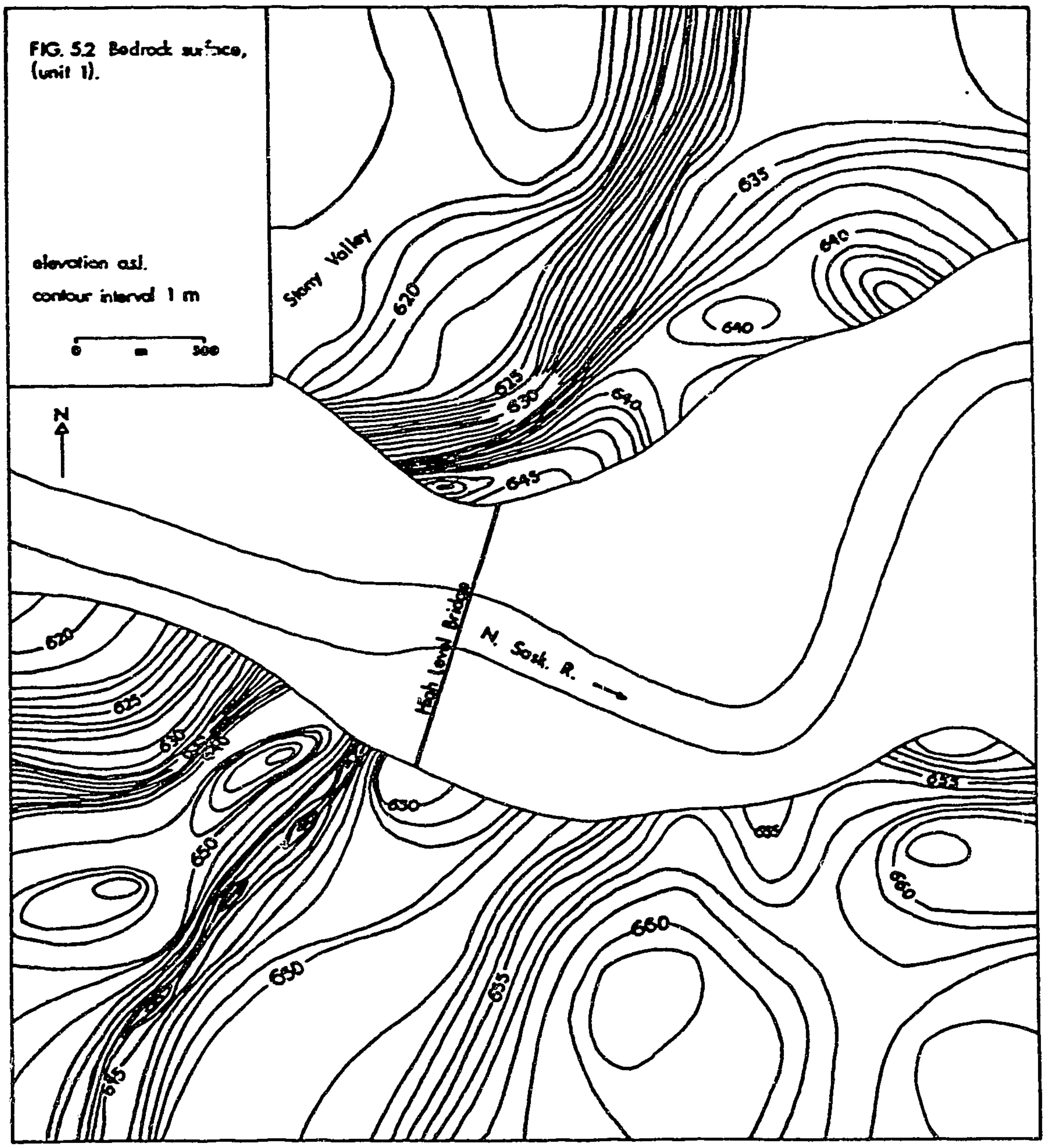


FIG. 5.2 Bedrock surface, (unit 1).

as mapped by Carlson (1967). The highest bedrock elevation is 663.2 m (holes 327 and 329), and the lowest is 615.5 m (hole 373).

A linear depression to the south of the river valley is oriented approximately northeast-southwest. A depression also occurs on the north side and at the edge of the river valley in the centre of the map area. The lowest elevation recorded in the depression on the north side is 639.9 m (hole 520), and the lowest on the south side is 636.6 m (hole 77), therefore there may be a low gradient to the southwest, although this is not consistent in all boreholes and there are not enough boreholes within the feature to determine the exact location of an axis. Both depressions are overlain by sand of unit 4.

Interpretation of Unit 1

Weakening of the upper part of bedrock may be due to the presence of an ancient weathering horizon, or overriding by glacial ice on bedrock highs. Fractures and joints are probably the combined result of regional uplift during the Tertiary, unloading by removal of overlying sediment or retreat of a glacier, shearing at the base of an overriding glacier and stress release during fluvial downcutting in the Holocene. Rubbly bedrock may be deformation till (Dreimanis and Schlüchter 1985) that formed through shearing at the base of a glacier. The predominance of claystone at the bedrock-sediment interface on bedrock highs suggests that the base of glacial erosion, or gouge zone, is preferentially located in a weaker bedrock horizon (cf. Christiansen and Sauer 1988).

The bedrock feature which appears to have extended from the depression on the north side at least to the southern edge of the map area, is not part of the integrated preglacial drainage system as it runs parallel to, and directly beside, the Stony Valley, and it appears to have a much lower gradient than preglacial tributary valleys previously mapped by Carlson (1967) and Kathol and McPherson (1975). It is interpreted to be a glacial meltwater channel, as it approximately parallels known regional ice movement direction and occurs on a bedrock convexity (cf. Sugden and John 1976). Other depressional areas along the edge of the river valley were probably formed by slumping of bedrock.

2. UNIT 2: SAND

Description

Discontinuous deposits of sand and gravelly sand occur over bedrock and under a diamicton complex. In areas where no diamicton complex is present, unit 2 cannot be defined and sand and gravel over bedrock is assigned to unit 4. In 87 boreholes which penetrate unit 2 the mean thickness is 7.2 m, with a standard deviation of 5.6 m and a maximum of 23.5 m (hole 489). The large standard deviation is caused by the very thick deposits of unit 2 which infill the Stony Valley in Upper Cretaceous bedrock.

Unit 2 consists predominantly of brown to grey-brown, fine to medium grained, well sorted sand (Table 5.1b). USCS classifications are SP and SM. In general the sediments are composed of stratigraphically lower quartzitic and local bedrock lithology sand, overlain by less well sorted sand of quartzitic and local mixed with granitic and metamorphic lithology of Shield provenance. The lower contact with bedrock is abrupt. The upper contact with diamicton of the diamicton complex is usually abrupt, but in places interbedded poorly sorted sand and gravel and thin diamicton beds (unit 2B) occur at the contact. The sediments are dry above the water table and moist below. The water table is commonly present in the lower part of the unit. Blow counts average above 100 (Table 5.1a). They generally are highest at the base of the unit and decrease upward, although locally gravel beds cause increased values.

Where unit 2 is greater than approximately 10 m in thickness, it consists predominantly of brown to grey, fine to medium grained, well sorted sand, composed of quartzitic and local bedrock lithology clasts and grains. In some areas it has iron-oxide staining within the top metre. Gravel beds occur, usually in the lower part of the unit. The upper part of the unit is commonly silty. Locally at the top of the unit sand is interbedded with gravel and diamicton containing material of Shield provenance (unit 2B). Blow counts are commonly highest at the base of the unit and decrease upward with a sudden increase at the top, usually to over 100.

Where unit 2 is less than approximately 5 m in thickness and discontinuous, it consists predominantly of brown, moderately sorted, medium grained sand, interbedded with gravel or diamicton in places (unit 2B). Sediments of mixed local and distal Shield lithology are common and comprise the entire unit in places. Blow counts are more variable and tend to average lower than where the unit is thick.

UNIT 2A: GRAVEL

In the boreholes which completely penetrate unit 2, gravel beds make up approximately 10% of the unit. They are up to 5 m in thickness and usually occur at the base or in the lower part of the unit where the unit is thick. Blow counts are usually higher in the gravel than in the sand.

UNIT 2B: SAND CONTAINING LENSES OR BEDS OF DIAMICTON

Discontinuous, poorly sorted sand and some gravel containing diamicton beds, occurs in places directly beneath the diamicton complex. The sediments contain material of Shield provenance. The diamicton beds are usually less than 1 m in thickness.

Distribution of Unit 2

Unit 2 is thick and continuous where it infills the buried Stony Valley in bedrock, and thin and discontinuous over bedrock highs (Fig. 5.3). The upper surface of the unit, (or the lower contact of the diamicton complex), is undulating and mirrors the bedrock topography, with a relief of approximately 30 m (Fig. 5.4).

Interpretation of Unit 2

All sorted sediments overlying bedrock and underlying

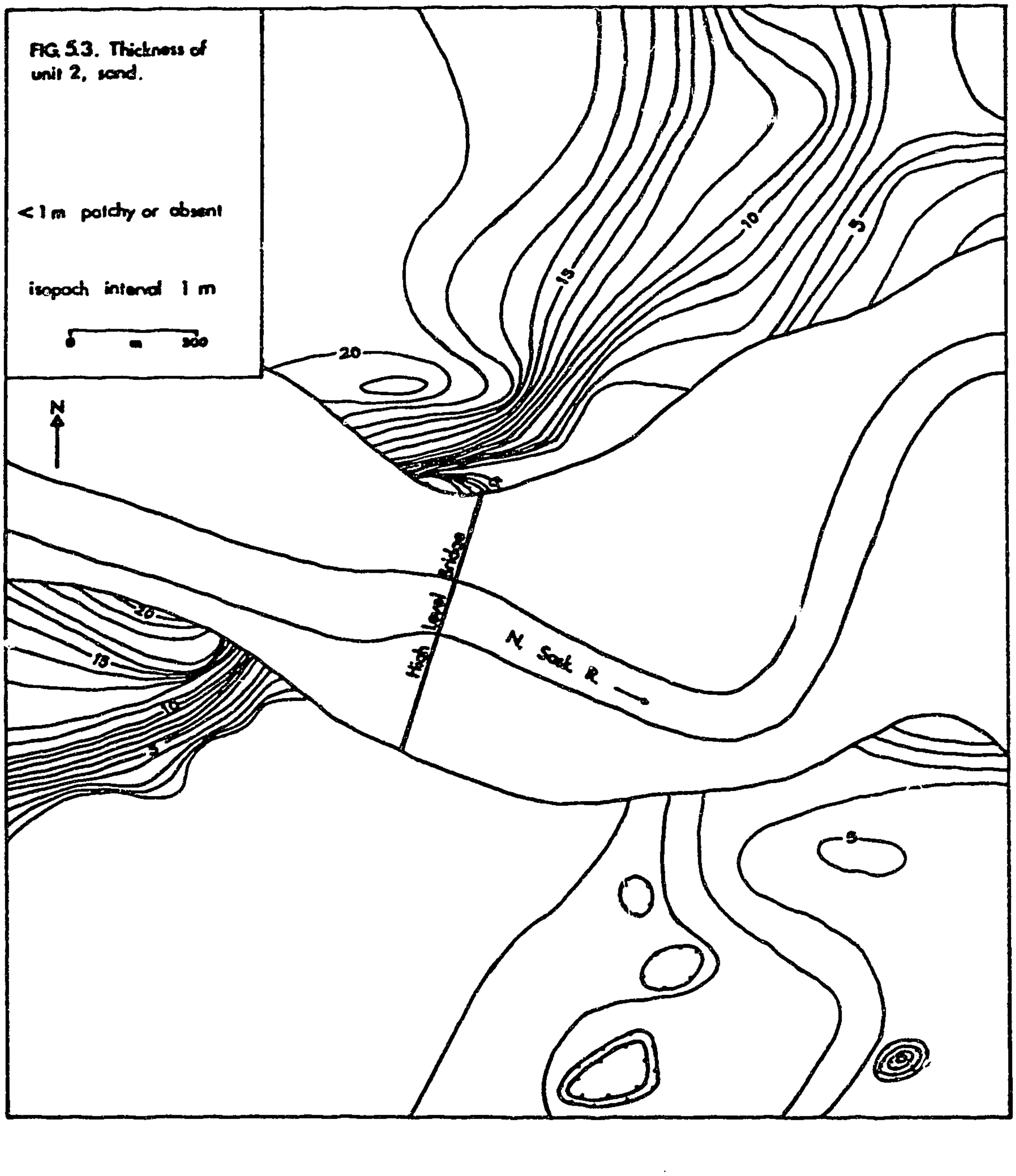


FIG. 5.3. Thickness of unit 2, sand.

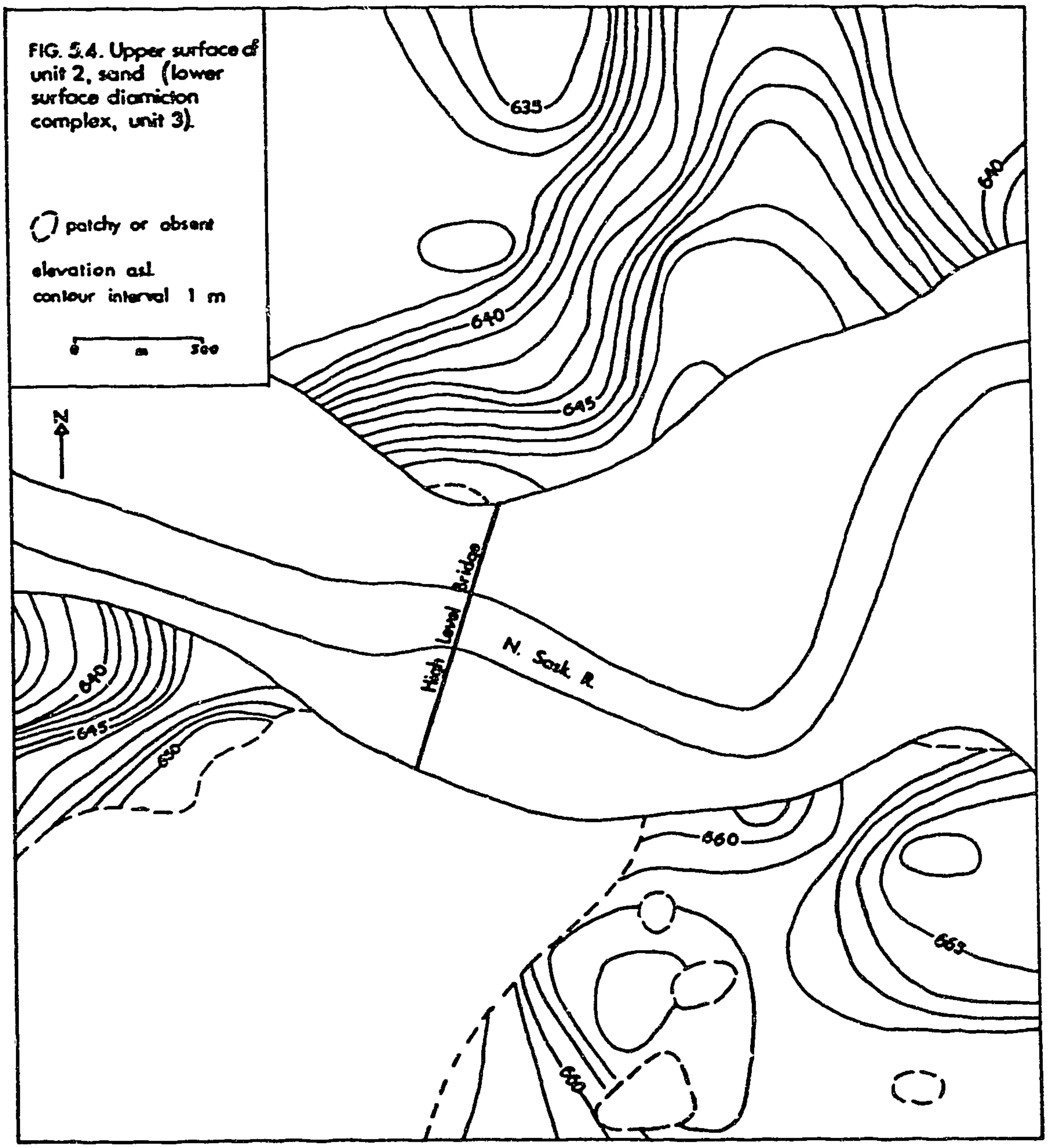


FIG. 5.4. Upper surface of unit 2, sand (lower surface diamicton complex, unit 3).

glacigenic diamicton in Edmonton have been correlated by Andriashek (1988) to the Empress Group of Whitaker and Christiansen (1972).

Thick continuous deposits infilling the Stony Valley and lacking Shield material are classified as preglacial Saskatchewan Gravels and Sands as defined by Stalker (1968). The sand, containing some gravel beds, was fluvially deposited, indicated by its location within a channel of the preglacial integrated drainage system mapped by Carlson (1967). High blow counts in the thick sand indicate high relative density probably due to the effects of age (cf. Skempton 1986), and possibly loading by glacier ice. Staining at the top could be the remainder of an ancient subaerial weathering horizon or iron-staining of a former periglacial active layer as observed by Westgate (1966). Higher blow counts at the top of the unit could result from a cemented horizon or discontinuous deposits of unit 2B which occur at the top of the unit.

Discontinuous and relatively thin deposits of unit 2 are mostly glacial in age as they commonly contain Shield provenance material, and are probably ice-proximal or subglacial sediments, as they are generally not well sorted, gravelly and commonly contain diamicton beds (unit 2B). High blow count variability is probably due to the presence of coarse grained sediments.

Most of the diamicton beds of unit 2B were probably deposited as debris flows, because they are thin and discontinuous and interbedding with sorted glacial sediments suggests they were deposited in association with meltwater.

The sharp, smooth upper contact with the diamicton complex probably represents the former erosional contact with the base of a glacier.

3. UNIT 3: DIAMICTON COMPLEX

Description

A complex consisting of a single diamicton or multiple diamictons containing material of Shield provenance overlies bedrock (unit 1) or sand (unit 2). The complex is defined as the thickest glacigenic diamicton unit that is not interbedded with clay of unit 6, and has a minimum thickness of 2 m unless it directly overlies bedrock. It contains lenses or interbeds of sorted sediment which together comprise less than half the total thickness of the complex. Where there is no complex, diamicton beds interbedded with sand and gravel are classified as unit 4C. In 213 boreholes which penetrated the complex the mean thickness of the unit was 9.4 m, with a standard deviation of 5.6 m and a maximum thickness of 29.4 m (hole 259).

Where the complex overlies bedrock the contact is abrupt and unconformable. A diamicton of predominantly local clast lithology is locally present at the contact. Where the complex overlies sand of unit 2, the lower contact is usually abrupt and unconformable, although in places thin diamicton beds are interbedded with poorly sorted sand and gravel (unit 2B). The upper contact of the diamicton complex is usually abrupt with sand of unit 4, silt of unit 5 or clay of unit 6.

The diamictons are matrix dominated. Names from the drill logs include till, clay till, sand till and silt till ("diamicton" henceforth replaces "till"). Some older logs have no specific matrix texture designations. Clay diamicton is the most common name, sand diamicton is common and silt diamicton is not as common. Texture differences indicated by grain size distributions are not always reflected in the name assigned to the unit because "clay diamicton" tends to be a general name for Edmonton diamictons.

Colour of the matrix is described as brown, grey-brown, grey or dark grey, with grey the most common.

Lenses and partings of sorted sediment (unit 3A) occur throughout the diamicton complex. The upper part of the complex commonly contains sand diamicton, numerous sand lenses or thinly interbedded sand and diamicton. The base of the complex can be sandy or contain numerous sand and gravel lenses, however this unit is usually thin and encountered infrequently. Very clayey, plastic matrix diamicton occurs discontinuously in the lower part or at the bottom of the complex. Stony horizons are not common, but occur at the base and throughout the complex, and at the base of some upper sand diamicton units. In places the upper complex is stony and the lower complex is not. Clasts of local bedrock up to 1.8 m in diameter are present. The clast lithology can have a higher local bedrock component than distal component in the lower part of the complex. Fissures are common throughout the complex, but are concentrated in the lower part in places. Vertical fissures have been observed to be iron-oxide stained.

Where the complex is relatively thick (greater than about 5 m) it is commonly described to have more than one type (usually two) of diamicton matrix texture and/or colour. Where the complex is relatively thin it commonly has uniform texture and colour. In 216 holes which penetrate the complex, more than one matrix texture is described in 44 holes, and more than one matrix colour is described in 113 holes. To determine whether diamictons of different texture and colour occur in certain stratigraphic positions, diamictons which had qualitative texture or colour specified on the drill logs have been classified as uppermost in the complex, lowermost in the complex, interbedded with other diamictons within the complex or comprising the entire complex (Table 5.2).

From Table 5.2, clay diamicton commonly comprises the entire complex, sand diamicton is commonly uppermost or within the complex and silt diamicton is commonly uppermost. Brown and grey-brown diamictons are commonly uppermost, grey diamicton is the lowermost unit or comprises the entire complex and dark grey diamicton is commonly lowermost and never uppermost. Considering texture and colour combined, generally in the complex, grey or dark grey clay diamicton is overlain by grey, brown, or grey-brown clay diamicton, which in turn is overlain in

TABLE 5.2. Stratigraphic positions in the diamicton complex of borehole diamictons of different qualitative matrix texture or colour.

	Number of Observations	Uppermost Position %	Lowermost Position %	Within Complex %	Comprises Entire Complex %
Diamictons of different TEXTURE only					
Clay	155	8	14	1	77
Sand	29	45	3	38	14
Silt	7	58	28	14	--
Diamictons of different COLOUR only					
Grey	112	1	54	2	43
Brown	95	69	1	1	29
Grey-brown	48	58	14	10	17
Dark Grey	22	--	77	--	23
Diamictons differentiated by TEXTURE AND COLOUR					
Grey Clay	87	1	60	1	38
Brown Clay	58	67	5	5	22
Grey-brown Clay	38	63	13	5	18
Brown Sand	18	61	5	28	6
Dark Grey Clay	17	--	88	12	--
Brown Silt	5	80	--	20	--
Grey-brown Sand	3	33	--	67	--
Grey Sand	3	33	--	67	--
Dark Grey Sand	2	--	50	50	--
Grey Silt	2	--	100	--	--

places by brown or grey sand diamicton.

In the boreholes where more than one qualitative matrix texture or colour is specified, approximately 30% contain diamictons of both different texture and different colour, and of those, approximately 50% of the contacts coincide. The textural contact is usually abrupt between two types and the colour change is commonly gradational through two or more colours. In 18% of the holes in which the diamicton complex had more than one texture specified, a sand lens is located between units of different texture. In 66% of the holes in which the diamicton complex had more than one colour specified, a sand lens is located between diamicton of a darker or grey colour below, and a lighter or brown colour above.

Average properties of diamictons of various types of qualitative matrix texture and colour within the complex (Table 5.3), indicate that differences are more pronounced and consistent between textural types. Sand diamicton generally has the highest relative density (blow counts) and strength and lowest Atterberg limits, and silt diamicton has the highest moisture content and lowest relative density and strength.

The average quantitative matrix composition of the diamicton complex is clayey silt and sand (Table 5.3b). USCS classifications are CL, CI, CI-SM, and SC-CL. Quantitative matrix grain sizes form four textural groups; clay-silt-sand, sand, clay and silt diamicton, which have distinctive properties (Fig. 5.5 and Table 5.4). This

TABLE 5.3a. Average properties of the diamicton complex, and diamictons of the complex, differentiated by qualitative matrix texture and/or colour. kPa = kilopascals. # = number of datapoints. SD = standard deviation.

	Water Content (%)	Blow Counts per 0.3 m (N)	Pocket Penetrometer (kPa)	Unconfined Compressive Strength (kPa)
DIAMICTON COMPLEX				
(MEAN)	15.5	83.0	359.0	423.0
(SD)	3.8	65.5	95.0	209.0
(#)	895	1180	84	82
TEXTURE				
Clay Diamicton	15.5	77.0	363.0	403.0
	3.5	34.0	93.0	187.0
	207	227	76	44
Sand Diamicton	15.5	94.5	298.0	486.0
	3.0	52.0	119.0	329.5
	45	48	6	7
Silt Diamicton	17.0	47.0	316.0	163.0
	3.5	35.0	57.0	---
	12	9	6	1
COLOUR (Colour and Texture)				
Brown Diamicton	15.5	84.5	304.0	419.0
	3.5	53.0	108.0	171.0
	89	100	11	13
(Brown Clay Diamicton)	15.5	79.0	330.0	315.0
	2.5	34.0	100.0	71.5
	39	45	9	4
(Brown Sand Diamicton)	15.5	83.5	183.5	373.5
	3.0	42.0	12.0	281.5
	17	20	2	3
Grey-brown Diamicton	15.0	91.5	412.0	361.0
	2.5	45.5	95.0	232.0
	53	55	22	13
(Gr-br Clay Diamicton)	14.5	76.0	411.5	332.5
	3.0	36.0	102.0	211.5
	34	36	19	8
(Gr-br Sand Diamicton)	15.0	89.5	417.0	348.0
	3.5	26.0	46.5	---
	5	5	2	1
Grey Diamicton	15.0	83.0	347.0	454.0
	2.5	45.5	86.5	214.0
	140	154	42	42
(Grey Clay Diamicton)	15.5	76.5	349.5	446.0
	2.5	33.0	87.0	196.5
	95	102	39	27
(Grey Sand Diamicton)	15.0	89.0	293.5	826.0
	2.0	53.0	118.0	---
	9	10	2	1
Dark Grey Diamicton	15.5	89.0	336.5	348.0
	2.5	57.5	61.5	79.5
	28	30	7	4
(Dk Gr Clay Diamicton)	16.0	74.5	336.5	403.5
	2.5	38.0	61.5	81.3
	23	24	7	2
(Dk Gr Sand Diamicton)	---	---	---	---

TABLE 5.3b. Average properties of the diamicton complex, and diamictons of the complex, differentiated by qualitative matrix texture and/or colour. LL = liquid limit, PL = plastic limit, PI = plasticity index. # = number of datapoints. SD = standard deviation.

	Atterberg limits LL (%)	PL	PI	Matrix Grain Size Clay (%)	Silt	Sand	Dry/Wet Density (g/m3)	
DIAMICTON COMPLEX								
(MEAN)	37.0	16.5	20.0	22.0	39.5	39.0	1.9	2.2
(SD)	8.5	3.0	8.0	10.0	10.5	12.0	0.1	0.05
(#)	80	80	80	39	39	39	4	8
TEXTURE								
Clay Diamicton	36.5	16.5	19.5	25.0	40.0	32.0	---	2.2
	8.0	3.0	7.5	9.0	3.0	9.0	---	0.05
	74	74	74	20	20	20	---	7
Sand Diamicton	25.0	17.5	7.5	12.0	38.0	49.5	---	2.1
	2.5	3.0	2.5	4.5	8.0	9.5	---	---
	3	3	3	6	6	6	---	1
Silt Diamicton	25.0	21.0	12.0	13.0	64.5	22.5	---	2.1
	2.5	0	5.0	7.0	5.0	2.0	---	0.06
	2	2	2	2	2	2	---	2
COLOUR (Colour and Texture)								
Brown Diamicton	30.5	17.0	13.0	15.0	39.5	44.5	---	---
	10.0	1.0	9.5	4.5	5.5	5.0	---	---
	8	8	8	9	9	9	---	---
(Brown Clay Diamicton)	34.0	17.5	16.0	15.0	42.0	42.0	---	---
	11.5	0.5	11.5	6.0	3.5	3.0	---	---
	5	5	5	5	5	5	---	---
(Brown Sand Diamicton)	24.5	17.5	7.0	15.5	36.0	48.0	---	---
	3.0	0.5	3.0	2.5	6.5	5.0	---	---
	2	2	2	4	4	4	---	---
Grey-brown Diamicton	34.5	16.5	18.5	29.5	44.0	26.5	1.8	---
	10.5	3.5	9.0	13.5	17.0	5.5	---	---
	13	13	13	3	3	3	1	---
(Gr-br Clay Diamicton)	35.0	16.0	19.0	29.5	44.0	26.5	---	2.2
	11.0	3.0	9.0	13.5	17.0	5.5	---	0.05
	12	12	12	3	3	3	---	5
(Gr-br Sand Diamicton)	---	---	---	---	---	---	---	---
Grey Diamicton	37.5	17.0	20.5	26.5	38.0	35.5	2.0	2.3
	7.5	3.0	6.5	10.5	6.0	11.5	0.05	---
	50	50	50	14	14	14	[illegible]	1
(Grey Clay Diamicton)	37.5	17.0	20.5	27.0	39.0	34.0	---	2.2
	7.5	3.0	6.5	10.5	3.5	10.5	---	---
	48	48	48	13	13	[illegible]	---	1
(Grey Sand Diamicton)	26.0	17.0	9.0	20.0	20.0	55.0	---	---
	---	---	---	---	---	---	---	---
	1	1	1	1	1	1	---	---
Dark Grey Diamicton	35.0	17.0	18.0	27.0	39.0	33.0	---	2.2
	8.0	2.5	9.5	---	---	---	---	---
	9	9	9	1	1	1	---	1
(Dk Gr Clay Diamicton)	36.5	17.0	20.0	27.0	39.0	33.0	---	2.2
	7.5	2.5	9.5	---	---	---	---	---
	8	8	8	1	1	1	---	1
(Dk Gr Sand Diamicton)	---	---	---	---	---	---	---	---

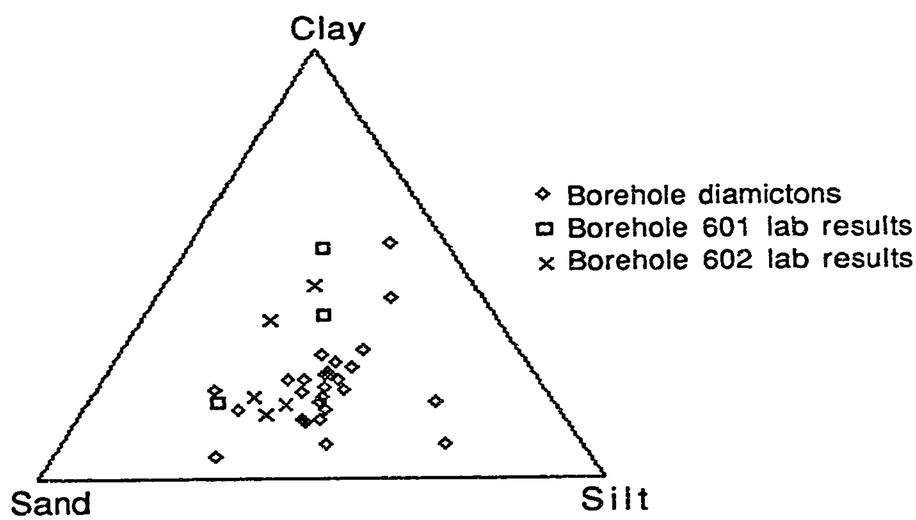


FIG. 5.5. Matrix grain size distributions for borehole diamictons in the diamicton complex.

TABLE 5.4 Average properties of four diamicton facies of the diamicton complex, differentiated by quantitative matrix texture and stratigraphic position. LL = liquid limit, PI = plasticity index, PP = pocket penetrometer, qu = unconfined compressive strength, kPa = kilopascals. # = number of datapoints. SD = standard deviation.

	Clay (%)	Silt (%)	Sand (%)	LL (%)	PI (%)	WC (%)	N (blow counts per 0.3 m)	PP (kPa)	qu (kPa)
CLAY-SILT-SAND DIAMICTON (middle stratigraphic position or comprises all of complex)									
Mean	22.0	40.0	38.0	38.0	21.5	15.5	62.0	270.5	
SD	3.9	2.9	3.6	3.9	3.7	2.7	28.2	109.5	
#	17	17	17	41	41	45	52	18	
SAND DIAMICTON (upper stratigraphic position)									
Mean	13.0	33.0	54.0	26.0	9.5	15.0	107.0		
SD	5.7	8.6	7.7	2.0	3.1	2.2	42.2		
#	11	11	11	20	20	18	28		
CLAY DIAMICTON (lower stratigraphic position)									
Mean	42.5	32.5	25.0	53.0	33.5	17.5	40.0	185.5	234.0
SD	8.5	7.9	10.1	6.3	5.9	3.8	15.2	64.4	---
#	7	7	7	11	11	11	11	6	1
SILT DIAMICTON (upper stratigraphic position)									
Mean	9.0	67.0	24.0	30.5	14.0	17.0	87.5		
SD	7.4	7.4	10.4	0.7	2.8	1.4	81.8		
#	4	4	4	2	2	2	5		

shows that unit names used on the borehole logs do not distinguish the clay-silt-sand from the clay diamicton, indicating that qualitative descriptions are too general. In the four-fold division, the difference between clay and sand matrix diamicton is in the proportion of clay to sand, with the silt content consistently between approximately 20 and 40%. Sand diamicton has a sand content greater than about 45%, and clay diamicton has a clay content greater than about 30%. Silt diamicton has a silt content greater than about 50%, at the expense of both clay and sand. Clay-silt-sand diamicton has a composition intermediate between the others. The stratigraphic positions of the diamictons remain the same, however, "clay" diamicton which was observed to commonly comprise the entire complex and less commonly to occur in a lowermost position, is now separated into clay-silt-sand diamicton, which is the most common diamicton in the complex and commonly comprises the complex, and clay diamicton, which is less common and occurs at the base of the complex. In holes 601 and 602 clay diamicton and sand diamicton make up the complex in both holes (Fig. 5.5), with grey-brown clay diamicton lowermost and brown sand diamicton uppermost (Fig. 5.6). Grain size distribution curves show that in both holes the lower diamicton is well graded and the upper diamicton shows some sorting, with the fine sand mode dominant.

Atterberg limits of the diamictons of the complex generally plot along the T-line in the range of glacial debris in transport (Fig. 5.7). Most of the values fall

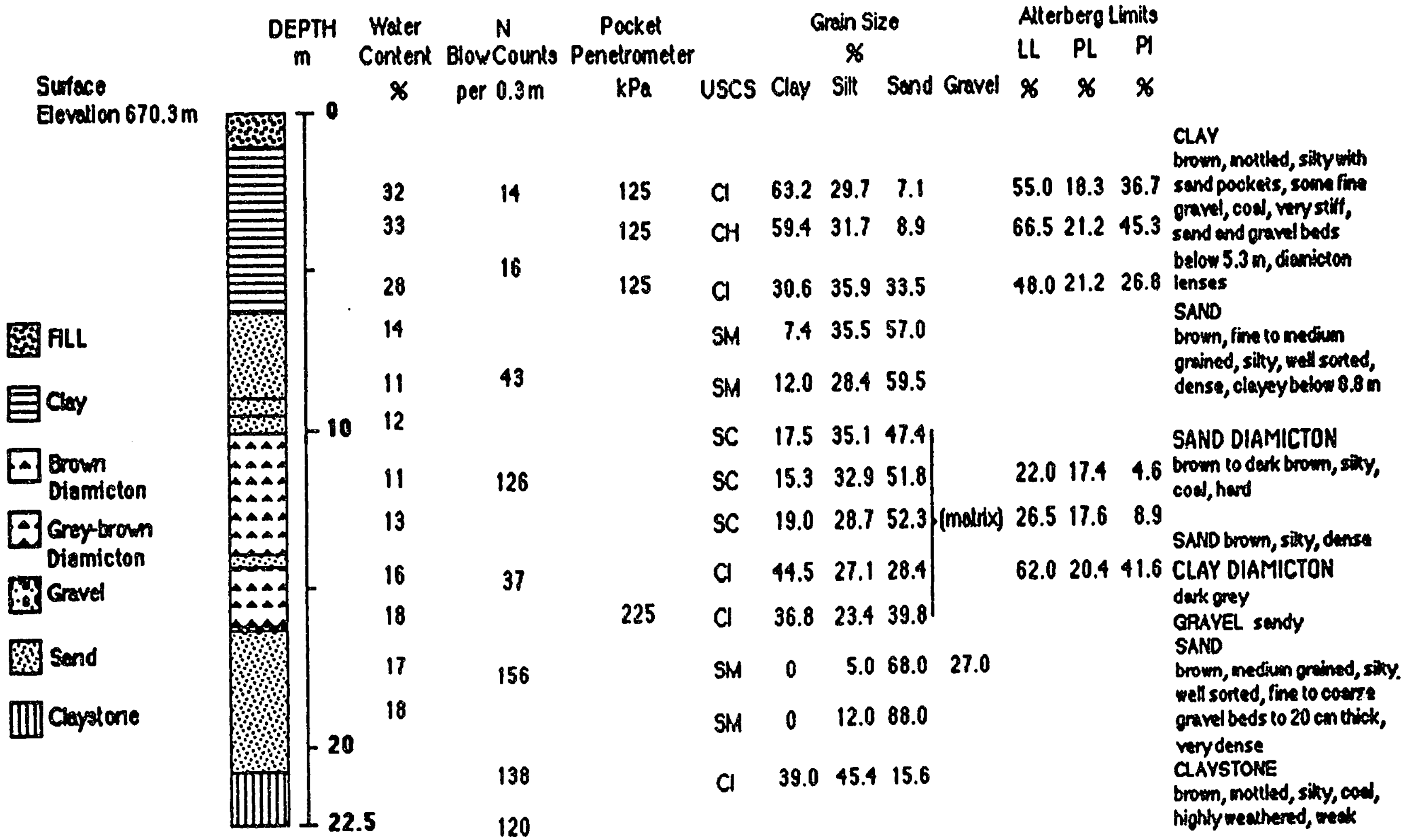


FIG. 5.6. Borehole 602. USCS = Unified Soil Classification System. Other symbols as for Table 5.1.

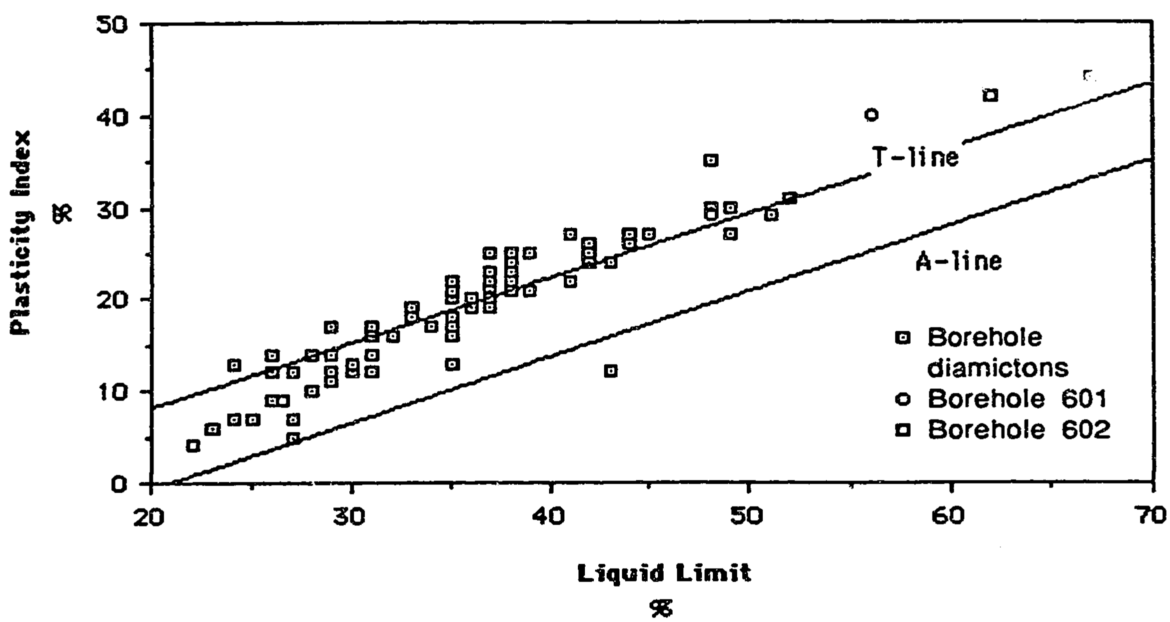


FIG. 5.7. Atterberg limits for borehole diamictons in the diamicton complex.

between the extremes from diamictons in holes 601 and 602. Three general groups within the T-line envelope have: a) liquid limits between about 20 and 31% representing sand and silt diamictons (although the sand tends to plot toward the left and the silt toward the right); b) liquid limits between about 32 and 45% representing clay-silt-sand diamicton; and c) liquid limits over about 48% representing clay diamicton. Diamictons with liquid limits lower than about 31% tend to be off and below the T-line, and diamictons with liquid limits above 48% are scattered off and around the T-line, indicating their grain size distributions differ from typical glacial debris in transport. Generally the liquid limit and plasticity index decrease upward within the complex.

Water contents are not very variable, although average water contents decrease with increase in grain size (Table 5.4). The water content tends to be slightly higher in the lower part of the complex, decreases upward and commonly has an abrupt increase at the top where a perched water table occurs within a metre above the top of the complex in overlying sand, silt or clay, (unit 4, 5 or 6, respectively). Usually a slight decrease occurs in the average water content above the water table, where it occurs within the complex. In 46 holes in which a water table and diamicton of more than one colour is recorded, about 25% of the water tables were within about 1 m of the elevation of colour change. Higher water contents in the lower part of the complex commonly coincide with increased clay content of the diamicton matrix and decreased blow count values.

Blow counts per 0.3 m (N) recorded within diamicton in the complex range between 8 and 800, with a mean of 83 (Tables 5.3a and 5.4). Values over about 250 are anomalous results from resistant boulders. The mean of values less than 250 is 77. The frequency distribution curve has a peak between 40 and 60, and a smaller peak between 100 and 120 (Fig. 5.8), which suggests that the complex consists mainly of two types of overconsolidated diamicton. The sand diamicton, which commonly occurs in upper stratigraphic positions, has an average blow count corresponding to the higher peak on the frequency distribution curve.

Where the complex is thicker than about 5 m, N is usually lowest in the bottom part of the complex and increases upward to its highest value somewhere within the complex, then decreases again upward (Fig. 5.9). The range in blow counts is higher in the upper part of the complex. A similar distribution emerged for blow counts above and below a locally continuous sand stratum within the complex in downtown Edmonton (Hardy 1985). In places the blow count is higher at the base of the complex, abruptly dropping to lower N values in overlying clay or clay-silt-sand diamicton. The abrupt or gradual increase of the average N value upward in the complex occurs in the lower to middle part of the complex. The change occurs in a variety of situations within the complex: a) reflecting

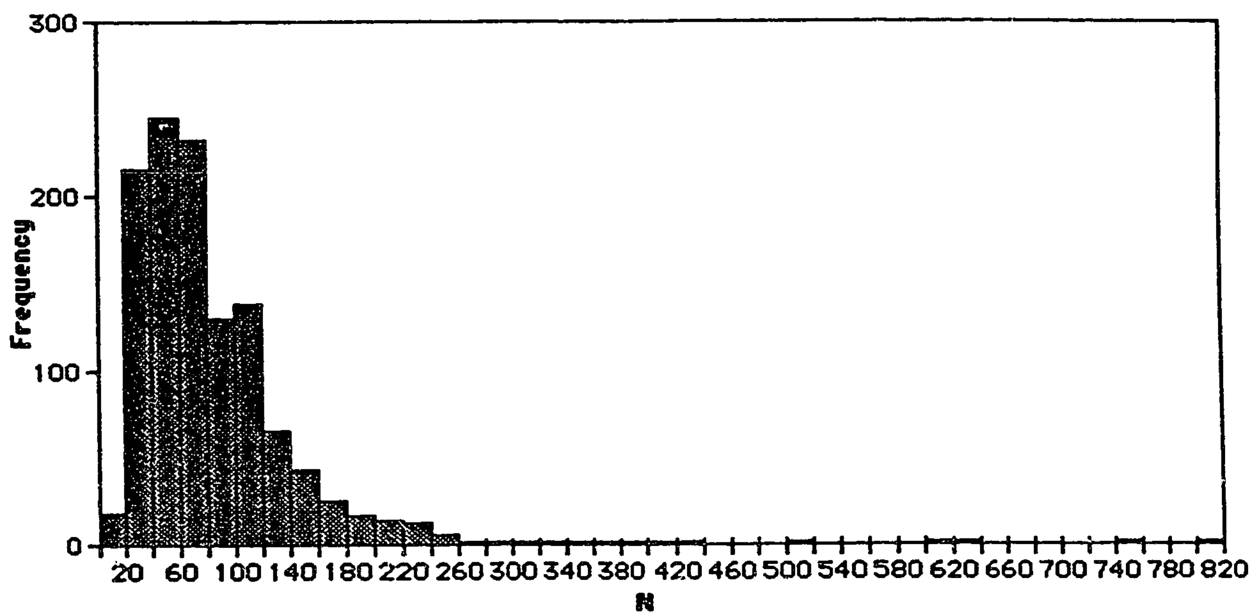


FIG. 5.8. Histogram of blow count values for borehole diamictons of the diamicton complex. N = blow counts per 0.3 m. Number of values = 1180; mean = 82.9; median = 67.0; standard deviation = 65.6. (Number of values of N less than 250 = 1160; mean = 77.2; median = 66.0; standard deviation = 45.0).

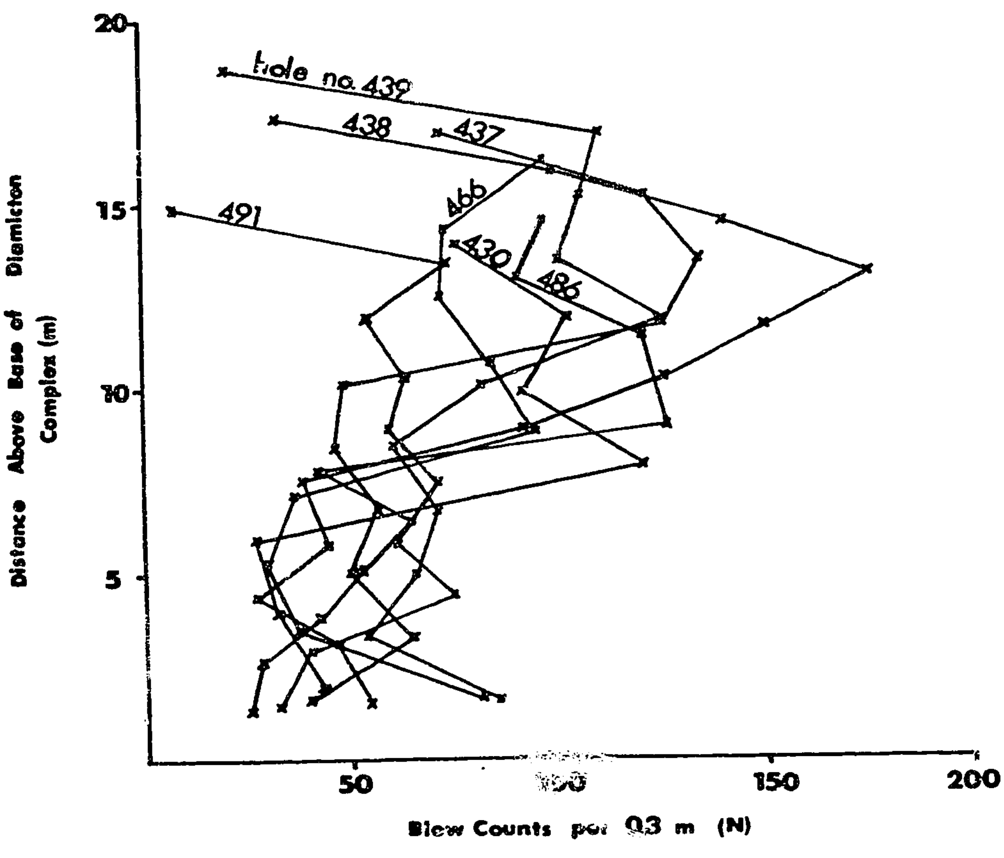


FIG. 5. Some blow count distributions in the diamicton complex, in boreholes where the complex is greater than 15 *m* thick.

no apparent change in diamicton character; b) in the vicinity of a matrix texture change from more clayey below to less clayey above; c) in the vicinity of a change from clay diamicton below to clay-silt-sand or sand diamicton above; d) in the vicinity of a sand lens, e) in the vicinity of a colour change from darker or grey below to lighter or brown above; or f) a combination of any of the latter four situations. Transition from clay diamicton to sand diamicton shows the largest, and least gradual, change. At the very top of the complex there can be an abrupt decrease to a low N value, commonly associated with a siltier diamicton, fissuring or a perched water table above the complex. Where the general pattern is absent, N can be consistently high or low, decrease upward through the complex or fluctuate through the complex. N is locally higher in stony diamicton.

Where N is less than about 30 the diamicton is considered "soft" (cf. Thomson et al. 1982). Soft zones are present in 57 boreholes and usually occur at the base, in the lower part or at the very top of the complex. Only one borehole showed a complex consisting entirely of soft diamicton. About 60% of the soft zones were in clay diamicton in the lower part, in a lower unit, or at the base of the complex. About 30% were in the upper part, usually at the top, of the complex in a sand or silt diamicton. The remainder occurred as isolated single values within the complex.

Pocket penetrometer and unconfined compressive strength values are variable but generally sand diamicton has the highest values and largest standard deviations (Tables 5.3a and 5.4). These values generally follow the trend of blow counts within a borehole.

3a. UNIT 3A: SAND LENSES

Lenses of sorted sediment having a minimum thickness of 10 cm were recorded in approximately 35% of the holes which penetrated the entire diamicton complex. The actual frequency is probably higher because some older logs show little or no detail of the sediments within the complex. The mean thickness of 101 lenses is 0.8 m, with a standard deviation of 0.7 m. All the lenses except one were less than 3 m in thickness. In hole 431, 5.1 m of sand is located between 8 m of underlying diamicton and 7.2 m of overlying diamicton. The underlying complex consists of grey clay-silt-sand diamicton. The overlying complex consists of grey clay-silt-sand diamicton overlain by brown clay-silt-sand diamicton, a gravel lens and another brown clay-silt-sand diamicton.

The lenses consist of moderately sorted, medium grained, brown or grey quartzitic sand, gravelly sand or silty sand. USCS classifications are SP, SM and SC. The lenses occur throughout the complex, but where the complex is thicker than approximately 10 m, they tend to be concentrated in the upper part. Lenses are commonly water saturated. Blow counts are usually high (Table 5.1a).

Distribution of Unit 3

The diamicton complex is thinner over bedrock highs and thicker over the buried Stony Valley in bedrock (Fig. 5.10). It is locally thicker where the upper part of the complex contains thicker and more abundant sand lenses, as in the north-central part of the map area (see cross sections A, C, and D; Figs. 5.17, 5.19, and 5.20). The lower contact is undulating, generally following the topography of the bedrock surface (Fig. 5.4). The upper surface of the unit is undulating to irregular, with a relief of approximately 20 m, and generally follows the topography of the bedrock but with irregular depressions in places (Fig. 5.11).

The complex is continuous, except where it is truncated by sand of unit 4, such as in an elongate area in the southern part of the map area, and just north of the river valley in the centre of the map area (Fig. 5.10). On the north side of the river, a depression on the surface of the complex deepens southward and the complex thins southward until it disappears north of the river valley. An upper depression and thinning of the complex also occurs to the west of the elongate feature in the south. The complex is also thin and absent in places in the southeast of the map area.

Interpretation of Unit 3

Unit 3 sediments are glacigenic, indicated by the presence of material of Shield provenance and the generally sharp lower contact of the complex, which is probably the location of the former base of overriding glacier ice. Glacigenic diamicton directly overlying bedrock on bedrock

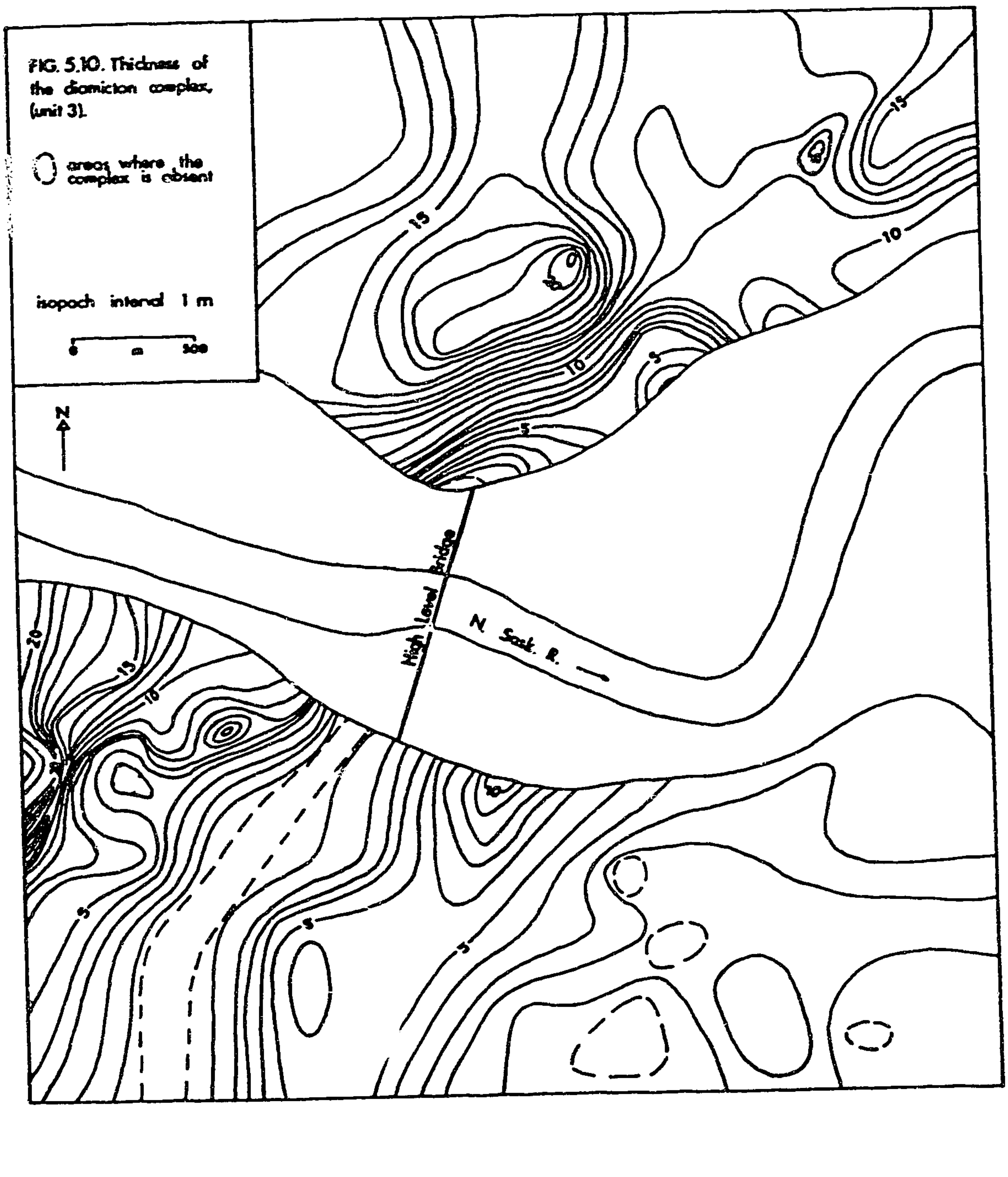


FIG. 5.10. Thickness of the diamicton complex, (unit 3).

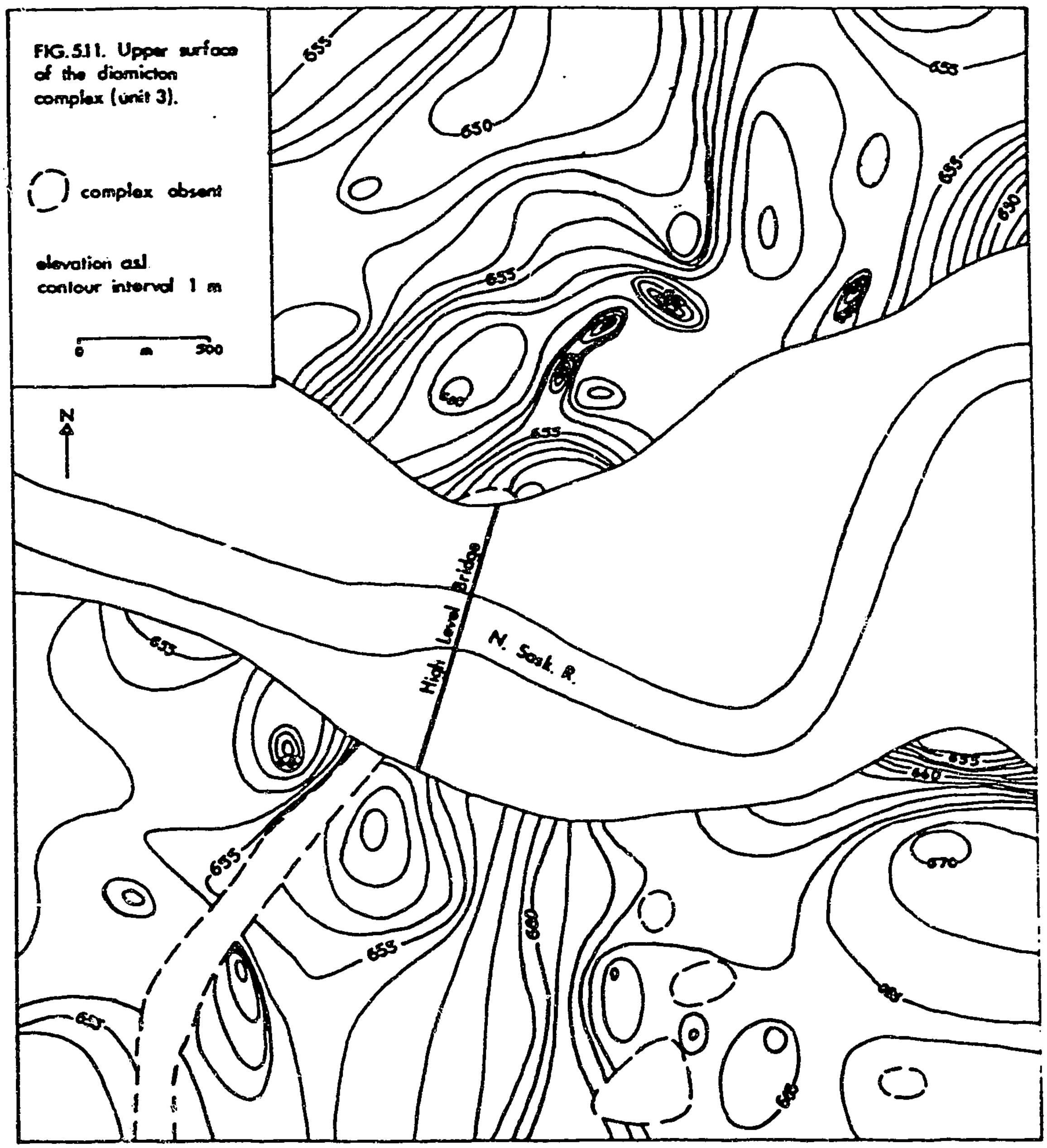


FIG. 5.11. Upper surface of the diamicton complex (unit 3).
complex absent
elevation asl
contour interval 1 m
0 m 500
N
High Level Bridge
N. Sask. R.
655
650
660
670

highs, indicates that the base of the glacier was probably in contact with, and eroded, the bedrock. Several diamictons can be differentiated by matrix texture and stratigraphic position. The base of the complex is locally marked by a soft, plastic, grey to dark grey, fissured diamicton with a high clay content. The high clay content could be from incorporation of local claystone bedrock or glaciolacustrine sediments. The localised nature of the deposit suggests it was selectively deposited or it was eroded by overriding ice. This diamicton may have been disturbed by overriding ice, possibly while saturated, resulting in its soft, fissured character. Sandy diamicton locally at the base of the complex probably resulted from incorporation of substrate material, but may indicate some sorting, possibly through deposition by flow. The bulk of the complex, composed of clay-silt-sand diamicton with lenses of sorted sediment throughout, was probably deposited predominantly by melt out, with englacially-formed sand lenses preserved, as interpreted by Catto (1984) and Shaw (1982) for most of the diamicton in the Edmonton area. At the base of the complex, the presence of boulder lines (cf. Boulton 1971), and the dense nature of the diamicton, suggests that some lodgement till may be present. Sand diamicton in the upper complex, in association with abundant sand lenses and stony in places, probably represents debris which underwent sorting and became interbedded with sand during deposition by debris flow, in association with meltwater. Silt diamicton at the top of the complex was probably deposited subaqueously by debris flow or turbidity current in a glaciolacustrine environment, as suggested by May (1977). Sand lenses which occur vertically throughout complex at no specific stratigraphic levels and do not always coincide with contacts between different diamictons, indicate that there is no continuous interdiamicton unit of sorted sediment.

The colour sequence in the complex, from dark grey up into brown, is interpreted to be a weathering effect due to oxidation, similar to that observed in other Late Wisconsinan glacigenic diamictons by Quigley and Ogunbadejo (1976), Eyles and Sladen (1981), Eyles et al. (1982), and Kulig (1985). Oxidation accounts for the lighter brown and grey-brown colours occurring in the upper part of the complex, in various types of diamicton, and to varying depths. The location of the oxidation boundary at sand lenses is because the lenses act as drainage blankets due to permeability differences (cf. Eyles et al. 1982, Sladen and Wrigley 1985). Coincidence of the colour boundary with contacts between diamictons of different matrix texture may also be due to permeability differences.

An overconsolidated "crust" can form by dessication and weathering (Soderman and Kim 1970; Quigley 1975; Quigley and Ogunbadejo 1976; and Eyles and Sladen 1981), which accounts for very high blow counts in the upper complex. Dessication results from groundwater lowering (Soderman and Kim 1970), and crusts have been observed to have an oxidised upper brown component and an unoxidised lower grey component (Quigley and Ogunbadejo 1976), therefore the colour and relative density boundaries within the sediment may not coincide, as observed within the Edmonton complex. Coincidence of the dessication boundary with the contact between a lower diamicton with a finer grained matrix and an upper diamicton with a coarser grained matrix and containing more sand lenses is probably due to permeability differences in the deposits. The lower part of the complex is less overconsolidated because it has not been dessicated. Its overconsolidation is probably due to subglacial deposition. This suggests that the difference in relative density between the clay-silt-sand and sand diamictons is a function of their stratigraphic position in relation to the dessication crust. However, soft zones in the complex probably reflect a particular diamicton type. Less extensive soft zones at the top of the complex probably occur in diamictons interbedded with sand, deposited glaciofluvially or subaqueously and that have not undergone dessication. Waterlain diamicton and mudflow deposits have lower bulk densities and much lower blow counts than subglacial till (Easterbrook 1964, Olmstead 1969). Differences in facility of drainage within the complex may have resulted in the different thicknesses and discontinuity of the crust. Soft zones at the base of the complex are probably restricted to the fissured clay diamicton in which the zones are commonly observed. Most blow counts, between about 40 and 80, throughout the complex, occur in diamicton which is probably overconsolidated subglacial till.

4. UNIT 4: SAND

Description

Discontinuous sand deposits occur overlying the diamicton complex or bedrock with an abrupt contact, and underlying silt (unit 5), or clay (unit 6), with gradational, and gradational and abrupt contacts, respectively. In 315 holes which penetrate the unit, the mean thickness is 7.7 m, with a standard deviation of 5.7 m and a maximum of 30.8 m (hole 611).

The sand is brown to grey, medium grained, and moderately sorted. USCS classifications are SM, SP, and SC. In places the sand is interbedded with silt, gravel or diamicton beds. Where Unit 4 overlies bedrock, the entire unit has been observed to contain Shield provenance material (boreholes 580 and 582). The lower contact is abrupt with bedrock or with the diamicton complex, except where sand and diamicton are interbedded (Unit 4C). The upper contact with silt or clay is usually gradational but abrupt in places.

A perched water table commonly occurs in Unit 4 above the diamicton complex. Where the diamicton complex is absent, the water table is commonly within several metres above bedrock.

Mean blow count values are low compared to unit 2 sand (Table 5.1a), although much of the unit occurs at equally great depths as unit 2 sediments, so they are subject to similar overburden pressures. In hole 549, unit 4 overlying bedrock has well sorted sand at the bottom with with a sharply higher blow count, averaging over 100.

4a. UNIT 4A: INTERBEDDED SAND AND SILT

Beds of interbedded sand and silt up to several metres in thickness commonly occur throughout the unit.

4b. UNIT 4B: GRAVEL

Gravel beds up to 9 m in thickness occur in places mainly in the lower part of the unit.

4c. UNIT 4C: SAND CONTAINING LENSES OR BEDS OF DIAMICTON

Unit 4C consists of sand containing diamicton beds usually less than 1 m in thickness and not exceeding the sand beds in thickness. The diamicton is matrix dominated with textures varying from clay to sand but is commonly silty or sandy. USCS classifications of the diamicton are CI and CL. It is usually brown, but can also be grey-brown, grey or rust-stained. The diamicton commonly contains sand lenses. The diamicton has higher water contents and lower blow counts on average than the underlying diamicton complex (Table 5.1a).

Distribution of Unit 4

Unit 4 is discontinuous (Fig. 5.12). A large deposit located in the central and southwestern part of the map area corresponds with a linear feature where the diamicton complex is absent and a bedrock channel is located. The sediments form an approximately linear ridge deposit which averages about 400 m in width, was at least 3.5 km long, before interrupted by the North Saskatchewan River valley, and extends southward off the map area.

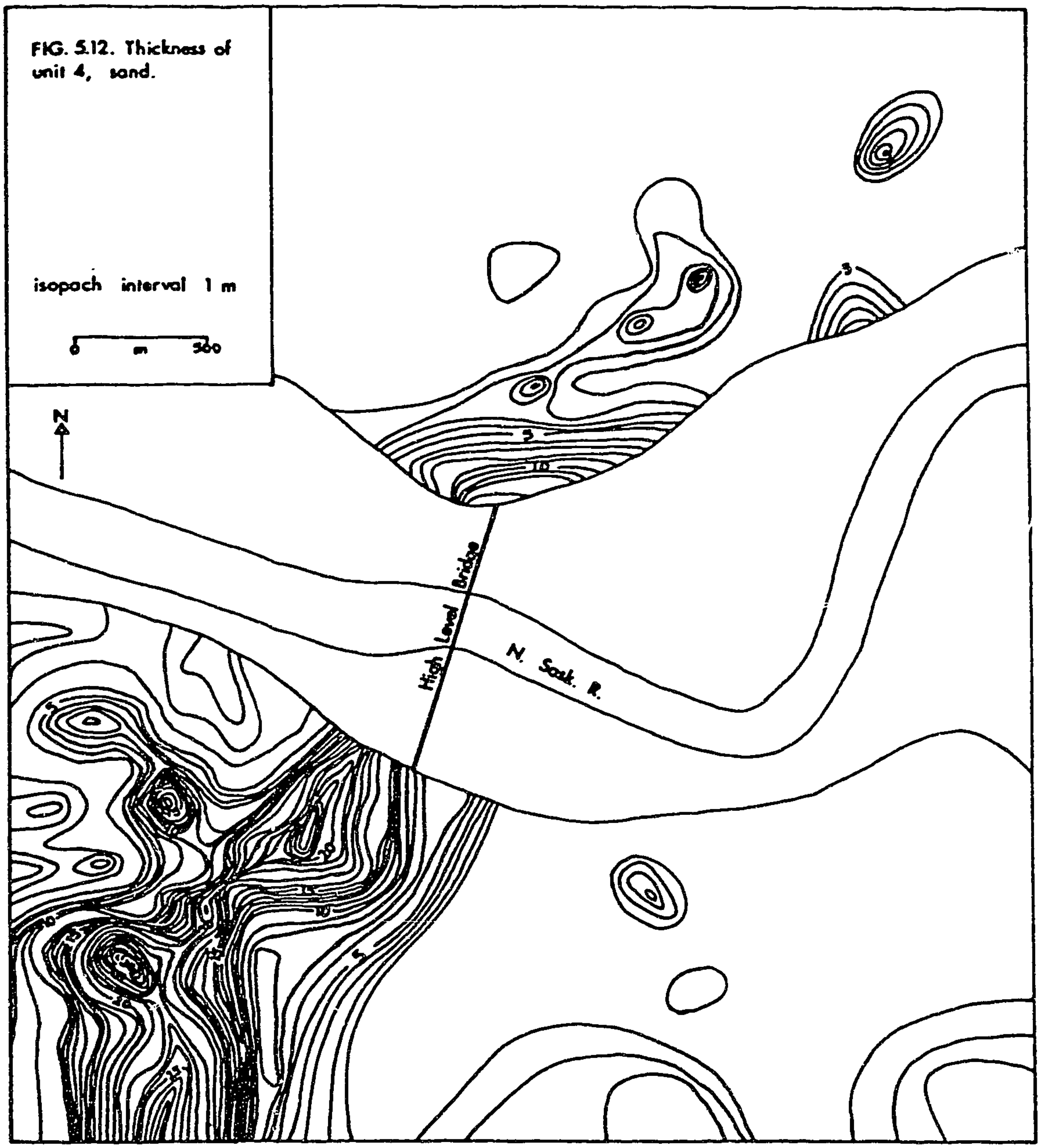


FIG. 5.12. Thickness of unit 4, sand.

Unit 4C is localised and usually occurs where the diamicton complex underlies unit 4 and in the peripheral zones of unit 4 where the complex is absent.

Interpretation of Unit 4

Sand of unit 4 is interpreted to have been deposited by glacial meltwater during ice retreat, indicated by its infilling of a linear channel which interrupts all stratigraphically lower sediments and its stratigraphic position immediately above the diamicton complex. Lack of a capping of subglacial diamicton also indicates the sediments are late glacial deposits. At the margins of the channel, unit 4 sand may have been deposited directly over sand originally underlying the diamicton complex before the complex was eroded, as indicated by sharply higher blow counts in the lower, denser, probably preglacial sand.

Erosion of the bedrock channel was probably accomplished by a highly detritus-charged, subglacial, ice-marginal stream, as postulated by Dingle (1971) for buried meltwater channels in the North Sea. Another possibility is that meltwater in an open ice-walled channel produced the linear feature (cf. Shaw 1972). Gravel beds are probably channel scour lags from several erosional episodes. The later deposits appear to have been deposited in several smaller channels, with adjacent glaciolacustrine environments where finer grained sediment was deposited. Discontinuous diamictons are probably debris flow deposits, suggested by their thin, lensoid geometry. Debris may have originated from the ice margin or from the diamicton complex where it formed the walls of meltwater channels. Interfingering of glaciofluvial, flow diamicton and glaciolacustrine sediments is suggestive of an environment of highly variable flow velocity, sediment supply and source area as in ice-marginal fan or delta environments (Evenson et al. 1977, May 1977, Shaw 1977, Gibbard 1980, Lawson 1981). Similar sediment associations have been observed in a broad subaqueous outwash ridge blanketed by glaciolacustrine clays (Diemer 1988).

5. UNIT 5: SILT

Description

Silt deposits discontinuously overlie the diamicton complex (unit 3) with an abrupt contact or sand (unit 4) with a gradational contact, and have a gradational contact with overlying clay (unit 6). In 216 boreholes which penetrate the unit, the mean thickness is 1.9 m, with a standard deviation of 1.6 m and a maximum of 7.9 m (hole 120).

The silt is brown, contains pebbles in places and usually fines upwards from sandy at the bottom to clayey at the top. USCS classifications are ML and SM-CL. Clay stringers are common. There are few diamicton lenses. The lower contact is abrupt with the diamicton complex, and gradational with sand. The upper contact is gradational with clay, and abrupt with diamicton of Unit 6A.

The silt has higher water contents and lower blow counts than underlying sand, and medium plasticity (Table 5.1a).

Distribution of Unit 5

Unit 5 is discontinuous and localised (Fig. 5.13). It commonly occurs peripheral to sand deposits of unit 4.

Interpretation of Unit 5

Silt was probably penecontemporaneously deposited with outwash sand, at the margins of, or between, major meltwater channels, as indicated by its distribution peripheral to deposits of unit 4. Silt interbedded with clay or directly underlying clay was probably deposited in a proglacial lake (cf. Gustavson 1975).

6. UNIT 6: CLAY

Description

Clay and silty clay overlies silt (unit 5), sand (unit 4), or the diamicton complex. It is generally the uppermost natural unit except in isolated areas where sand of unit 7 occurs. In 571 boreholes which penetrate the unit, the average thickness is 4.7 m, with a standard deviation of 1.9 m and a maximum of 11.5 m (hole 253).

Unit 6 consists of brown to grey-brown clay and silty clay (Table 5.1). USCS classifications are CH, CI and CL-ML. The clay is usually described as having a mottled appearance and a nuggetty (blocky) structure. Laminae are identified in places but the sediment is usually disturbed, probably in most cases by sampling processes. The clay contains silt, sand, and diamicton stringers, and some pebbles. The unit is commonly very silty at the base and fines upward.

In the middle of the unit the water content is usually

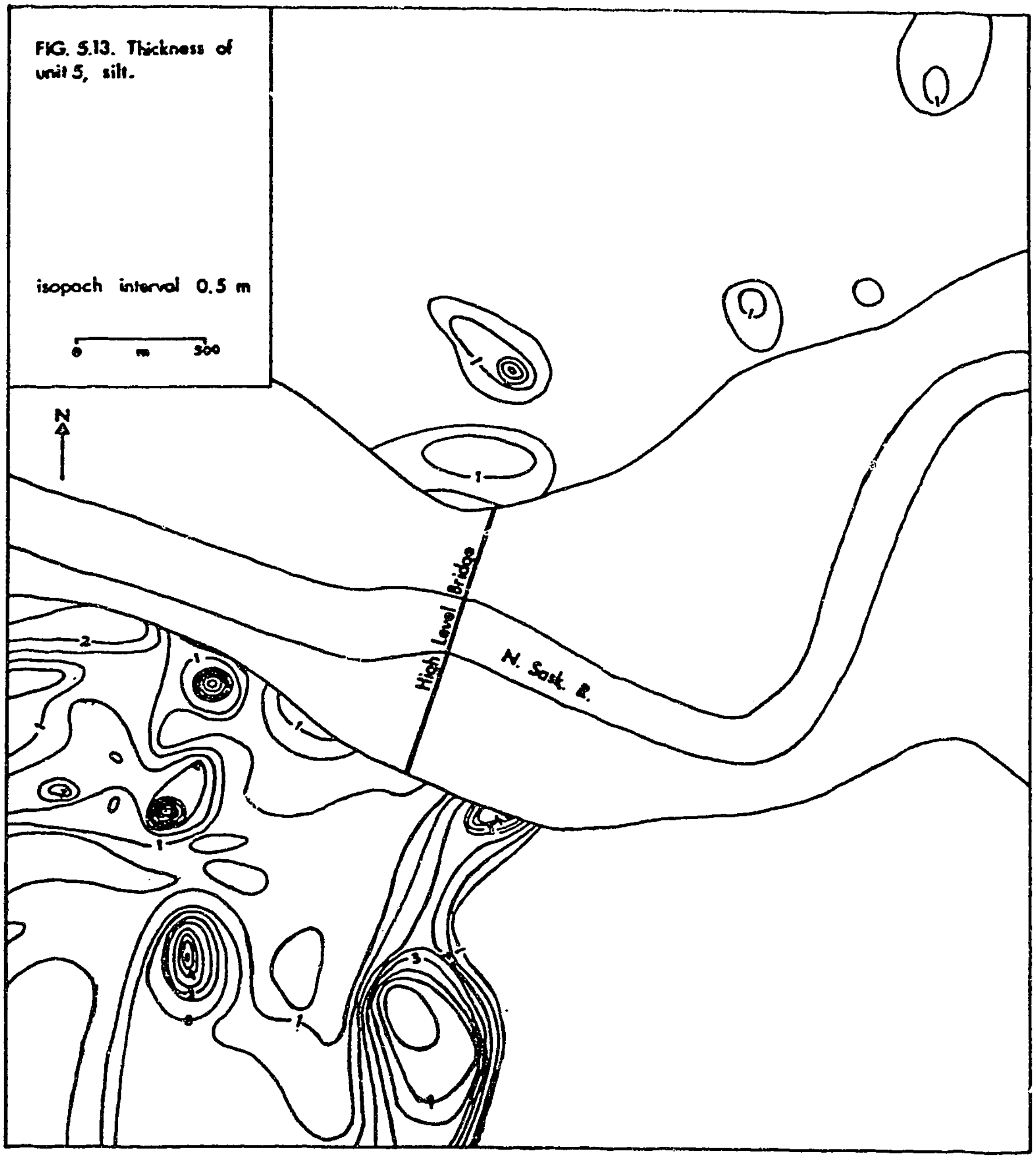


FIG. 5.13. Thickness of unit 5, silt.

highest, the blow counts are lowest and the Atterberg limits highest.

6a. UNIT 6A: CLAY CONTAINING LENSES OR BEDS OF DIAMICTON

Localised lenses or beds of brown diamicton interbedded with clay and silt are common and usually occur at the base of unit 6, overlying silt of unit 5, but can also be interbedded with clay. They are usually less than about 1 m in thickness, have a silt matrix, and high water contents and low blow counts relative to diamictons of units 3 and 4C (Table 5.1).

Unit 6A was encountered in ±10 boreholes. Unit 4 was present in approximately 85% of the boreholes in which unit 6A occurred.

Distribution of Unit 6

Unit 6 blankets the map area to the north and south of the North Saskatchewan River valley (Fig. 5.14). It is thicker over the buried Stony Valley in bedrock and thinner over bedrock highs or where it overlies glaciofluvial sand of unit 4.

Interpretation of Unit 6

Clay and silty clay were probably deposited in a proglacial lake, for the laminae are probably rhythmites (cf. Gustavson 1975), and diamicton lenses and pebbles were probably melted out of floating brash ice. Silty diamictons occurring at the base of the unit may have been formed during an episode of debris flows which may have occurred during formation of the lake, when water may have saturated and destabilised preexisting diamicton deposits.

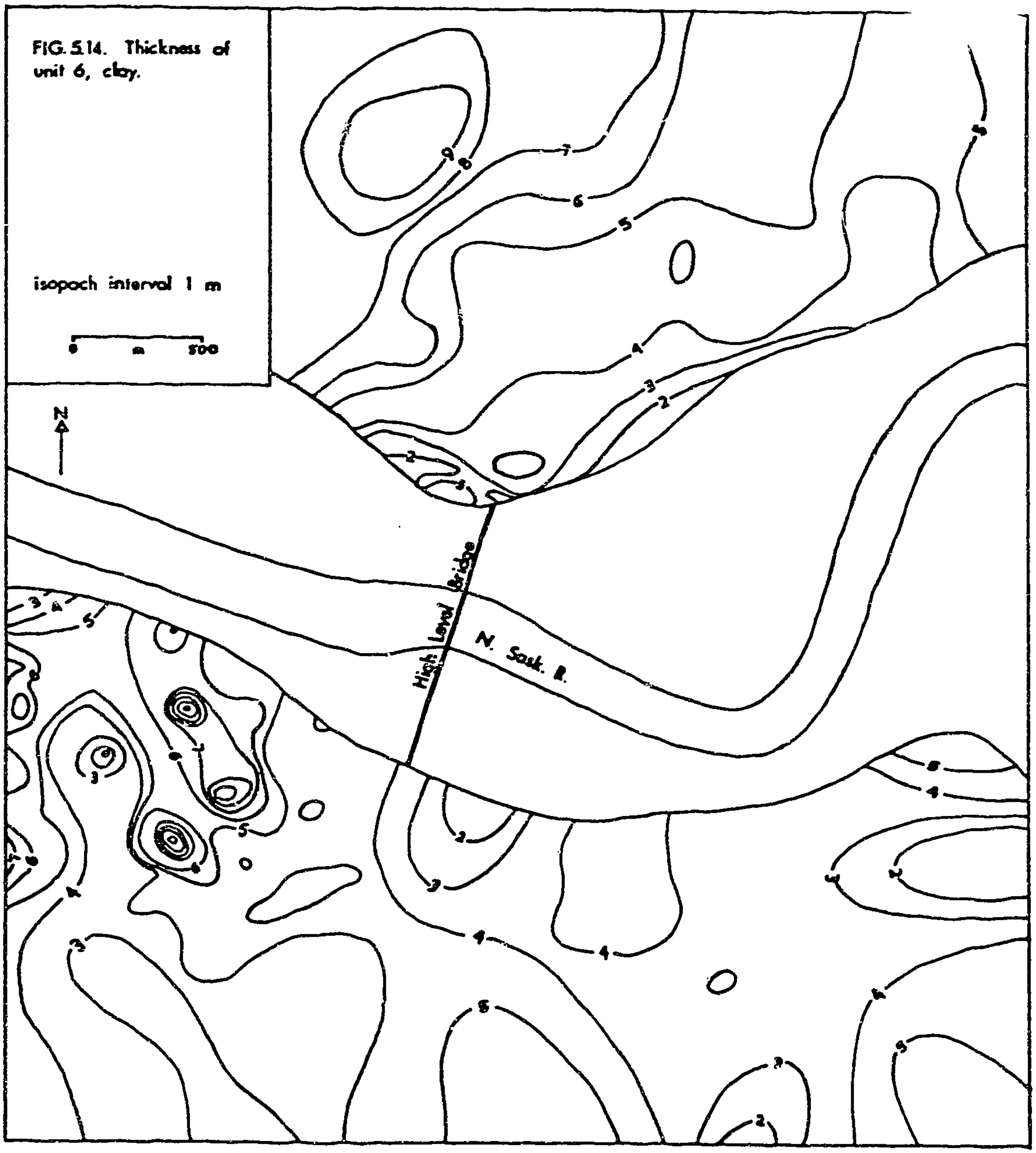


FIG. 5.14. Thickness of unit 6, clay.

Lower Atterberg limits and water contents in the lower part of t' ... it reflect a siltier texture. Low water contents and higher blow counts in the upper part reflect dessication and weathering. The nuggetty structure could be fissuring due to shrinkage during dessication. Where the unit is thin, sediment influxes may have been low, current activity may have precluded deposition or draining water eroded the unit during emptying of the lake. In places the unit was probably anthropogenically removed.

7. UNIT 7: SAND

Description

Unit 7 consists of discontinuous deposits of well sorted, medium grained sand, overlying clay of unit 6. In places sand of unit 7 may overlie sand of unit 4 and neither unit can be defined. In 32 boreholes which penetrate the unit, the average thickness is 1.3 m, with a standard deviation of 0.7 m and a maximum of 3.5 m (hole 450).

Distribution of Unit 7

Unit 7 was encountered in relatively small areas adjacent to the river valley, in the south central and north central parts of the study area (Fig. 5.15).

Interpretation Of Unit 7

Unit 7 sand was probably fluvially deposited by the early postglacial North Saskatchewan River, indicated by its distribution adjacent to the river valley, possibly on upper terrace levels of the North Saskatchewan River.

8. UNIT 8 FILL

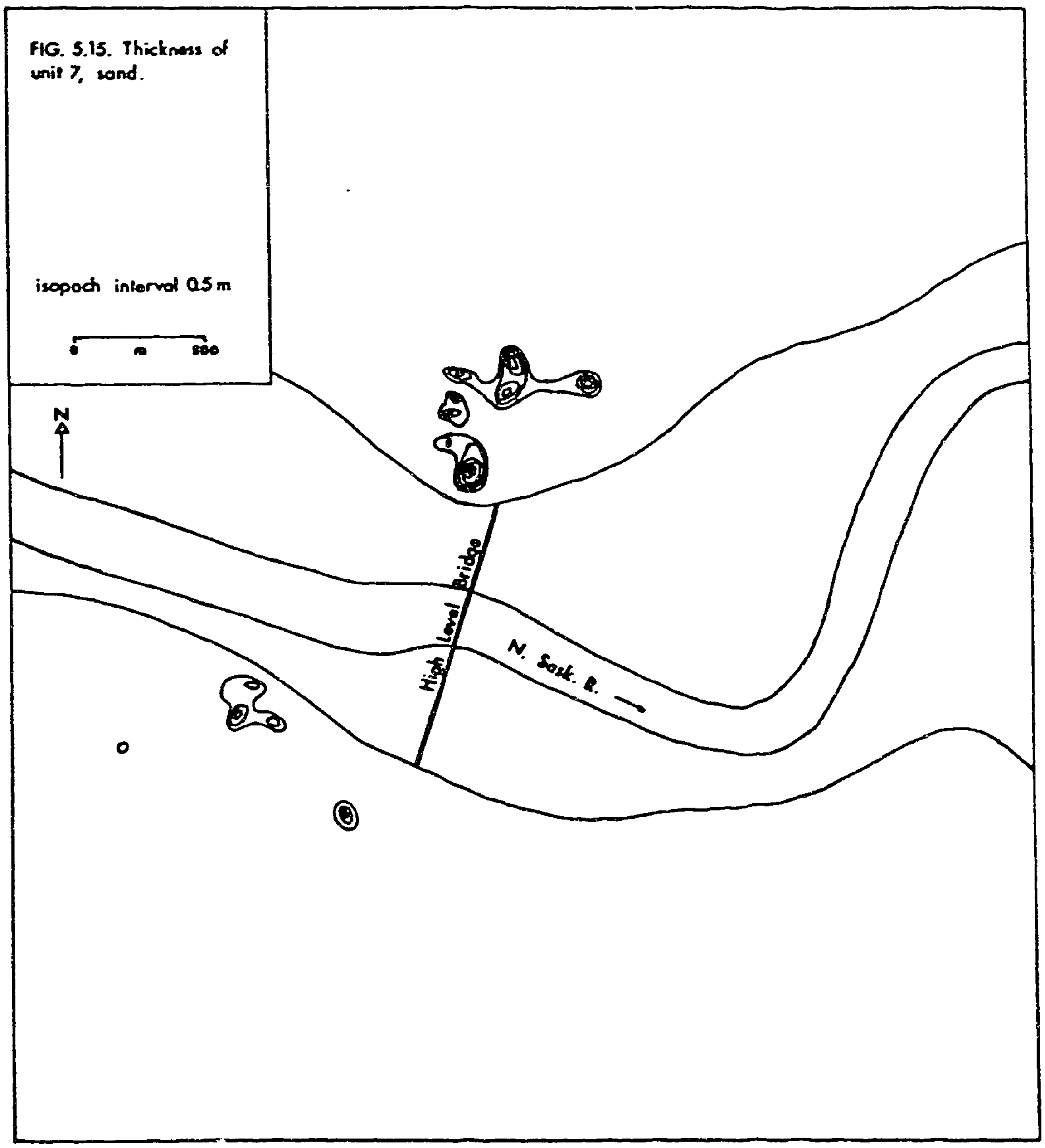


FIG. 5.15. Thickness of unit 7, sand.

Localised deposits of a wide variety of anthropogenically disturbed sediment overlie clay (unit 6), silt (unit 5), sand (unit 4), the diamicton complex (unit 3), or North Saskatchewan River valley sediments, and are always the uppermost unit. The material consists of poorly to moderately sorted, fine to coarse grained sediment, commonly containing anthropogenic debris such as brick. The lower contact is abrupt and unconformable.

Surface Topography

The surface topography north and south of the river valley is gently undulating, with a relief of approximately 18 m (Fig. 5.16). The blanket distribution of unit 6 glaciolacustrine clay results in a generally smooth surface. Anthropogenic activity has altered the surface only locally.

The surface trough across the northwest corner of the map overlies the buried Stony Valley in bedrock. Elevated areas are the result of either the presence of underlying bedrock highs, as in the southeastern part of the map area, or underlying relatively thick diamicton of unit 3 or sand of unit 4, as in the southwestern and north-central areas of the map. Where thick deposits of units 3 and 4 occur, the elevated areas are probably composed of superimposed subaqueous fans forming ridges in standing water as the ice margin retreated (cf. Banerjee and MacDonald 1975). The broad, low morphology is similar to a ridge composed of subaqueous outwash described by Deimer (1988).

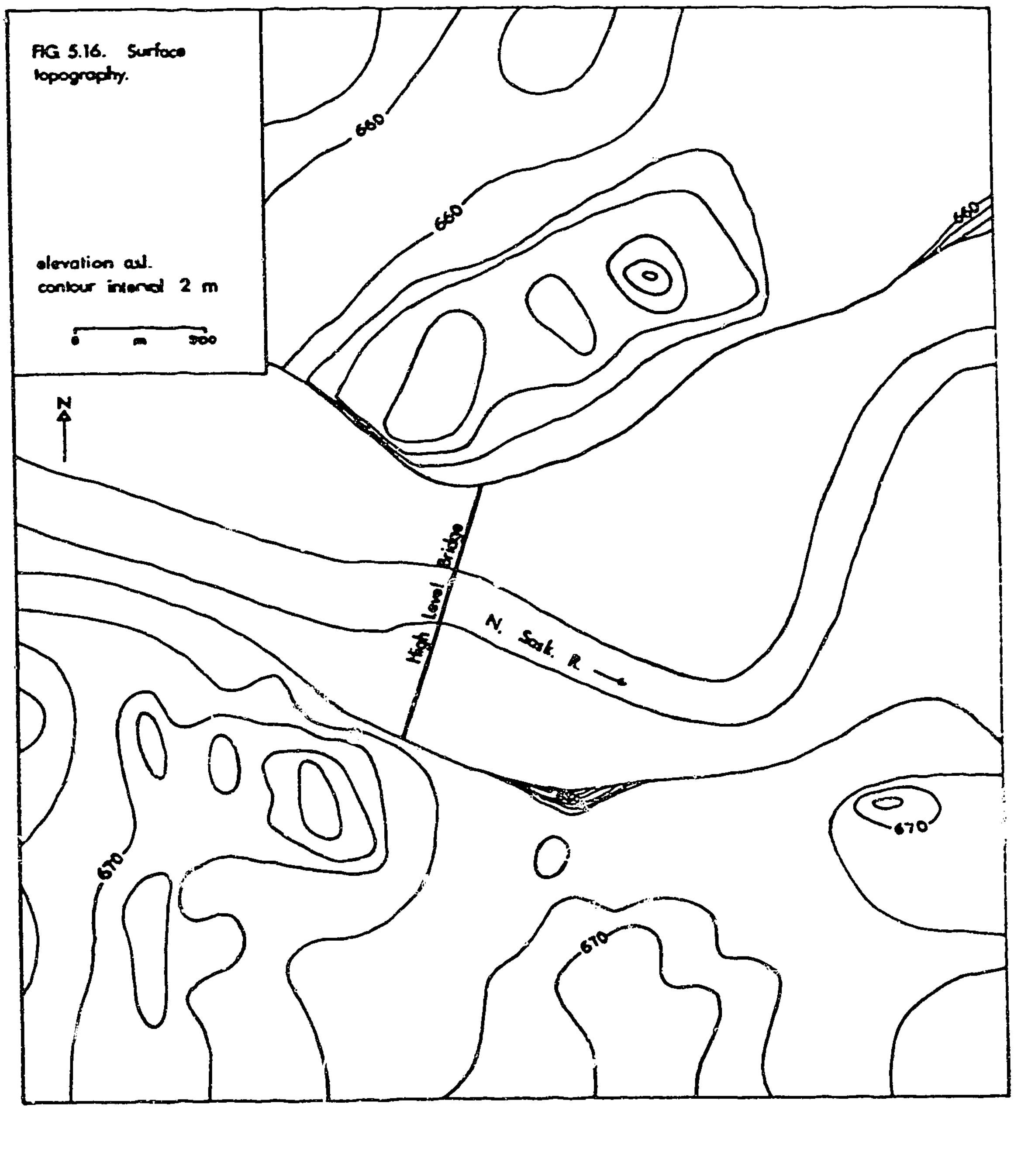


FIG. 5.16. Surface topography.

C. Cross Sections

Twelve cross sections show the lateral variability of the sediment units in central Edmonton. Locations of the sections are shown on Fig. 5.1 (in pocket). Some boreholes in the sections are not located directly on the section line, but are located within 30 m. Sediment unit names and symbols used for the cross sections are in Table 5.5. On the north side of the river valley, sections A to D are positioned to make use of the high borehole density along the LRT route. On the south side of the river valley, section E is positioned northeast-southwest (approximately north-south), and is located due south of section D. Sections F to I are positioned north-south, intersecting as many holes reaching bedrock as possible. Sections J and L are positioned northwest-southeast, and section K is positioned west-east, mainly intersecting boreholes on the university campus.

On the north side of the river valley, units 2, 3, and 6 are relatively continuous (sections A, B, C, and D; Figs. 5.17, 5.18, 5.19, and 5.20). The diamicton complex shows the most lateral variation. The lack of detail from some boreholes produces areas in the cross sections where it seems that little variation occurs, such as in section A (Fig. 5.17) in the vicinity of boreholes 369 and 376, and in section B (Fig. 5.18) on the northwest side. The lower contact of the complex is generally smooth, and makes contact with bedrock over the bedrock high (section B; Fig. 5.18). In all of the sections north of the river valley,

TABLE 5.5. Borehole sediment unit names and symbols for cross sections.

Units (note: complete unit descriptions in text)

8 Fill. Anthropogenically disturbed material of various types as the uppermost unit.

7 Sand. Postglacial fluvial sediments overlying glaciolacustrine clay.

6 Clay. Glaciolacustrine sediments overlying the diamicton complex or glaciofluvial sand or silt.
 6A Clay containing lenses or beds of diamicton.

5 Silt. Glaciofluvial or glaciolacustrine sediment overlying the diamicton complex or glaciofluvial sand, and underlying glaciolacustrine clay or fill.

4 Sand. Glaciofluvial sediments overlying the diamicton complex or bedrock, and underlying glaciofluvial or glaciolacustrine silt or clay, or fill.
 4A Interbedded sand and silt.
 4B Gravel.
 4C Sand containing lenses or beds of diamicton.

3 Diamicton Complex. The thickest unit of glacigenic diamicton present in a borehole with a minimum thickness of 2 m (unless directly overlying bedrock).
 3A Lenses of sand, silt, or gravel, which altogether comprise less than 50% of the complex thickness in a borehole.

2 Sand. Preglacial and/or glacial fluvial sediments overlying bedrock and underlying the diamicton complex.
 2A Gravel.
 2B Sand containing lenses or beds of diamicton.

1 Bedrock. Poorly-consolidated Upper Cretaceous claystone with interbedded sandstone and siltstone, and some coal and bentonite seams.

Symbols

Lens

Clay

Silt

Sand

Gravel

Diamicton

Colour boundary in diamicton complex

Upper boundary of lower soft zones in diamicton complex

Boulder of local Cretaceous bedrock

Stony

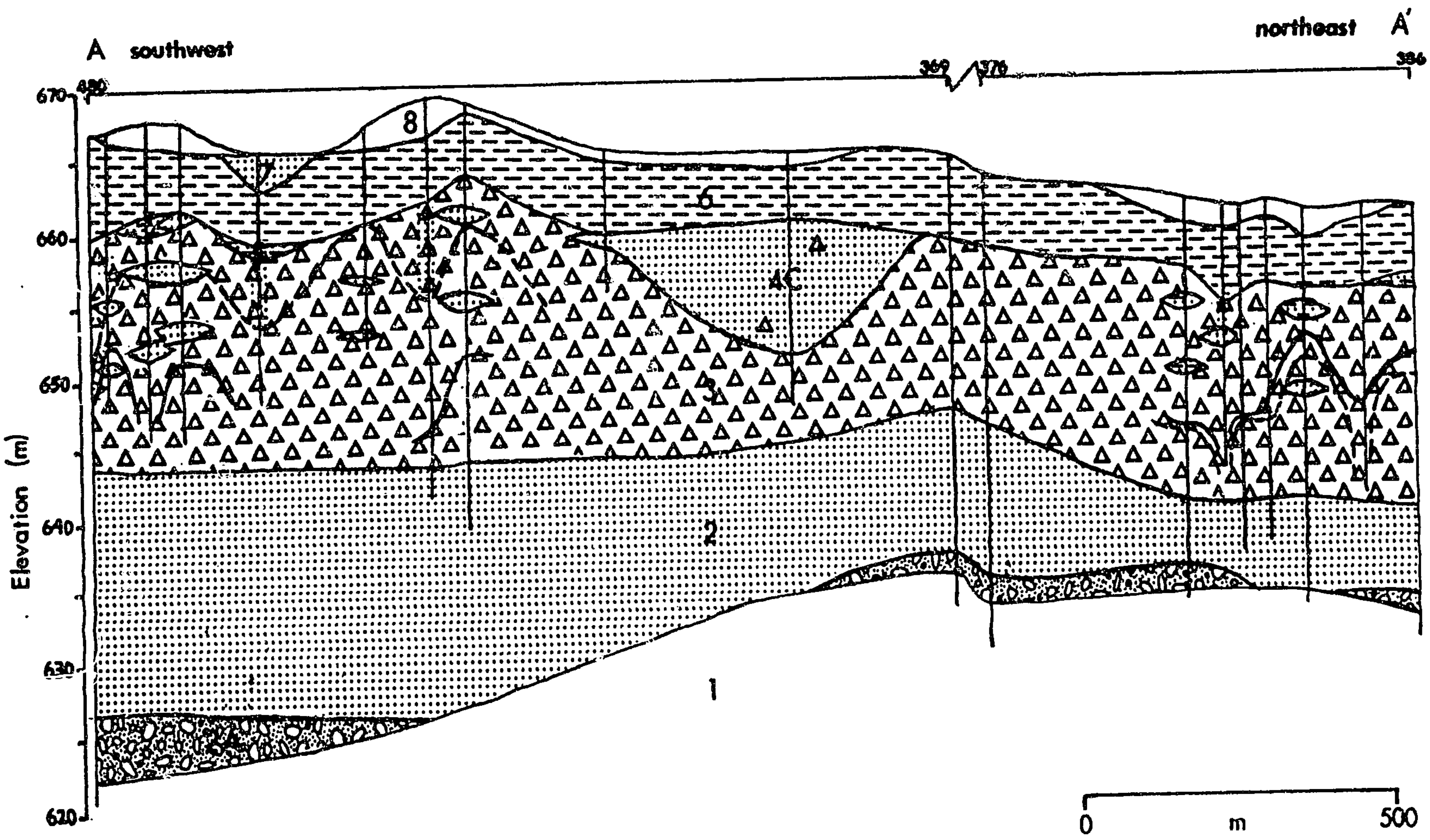


FIG.5.17. Cross section A. Location on Fig.5.1. (in pocket). Unit names and symbols in Table 5.5.

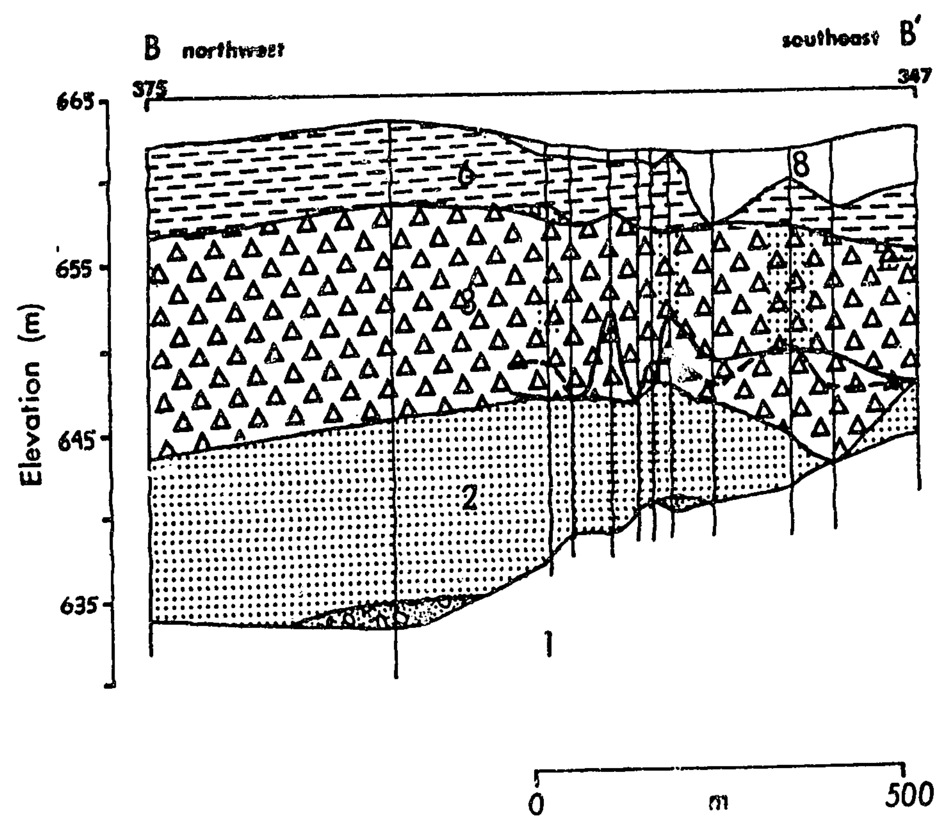


FIG. 5.18. Cross section B. Location on Fig. 5.1, (in pocket). Unit names and symbols in Table 5.5.

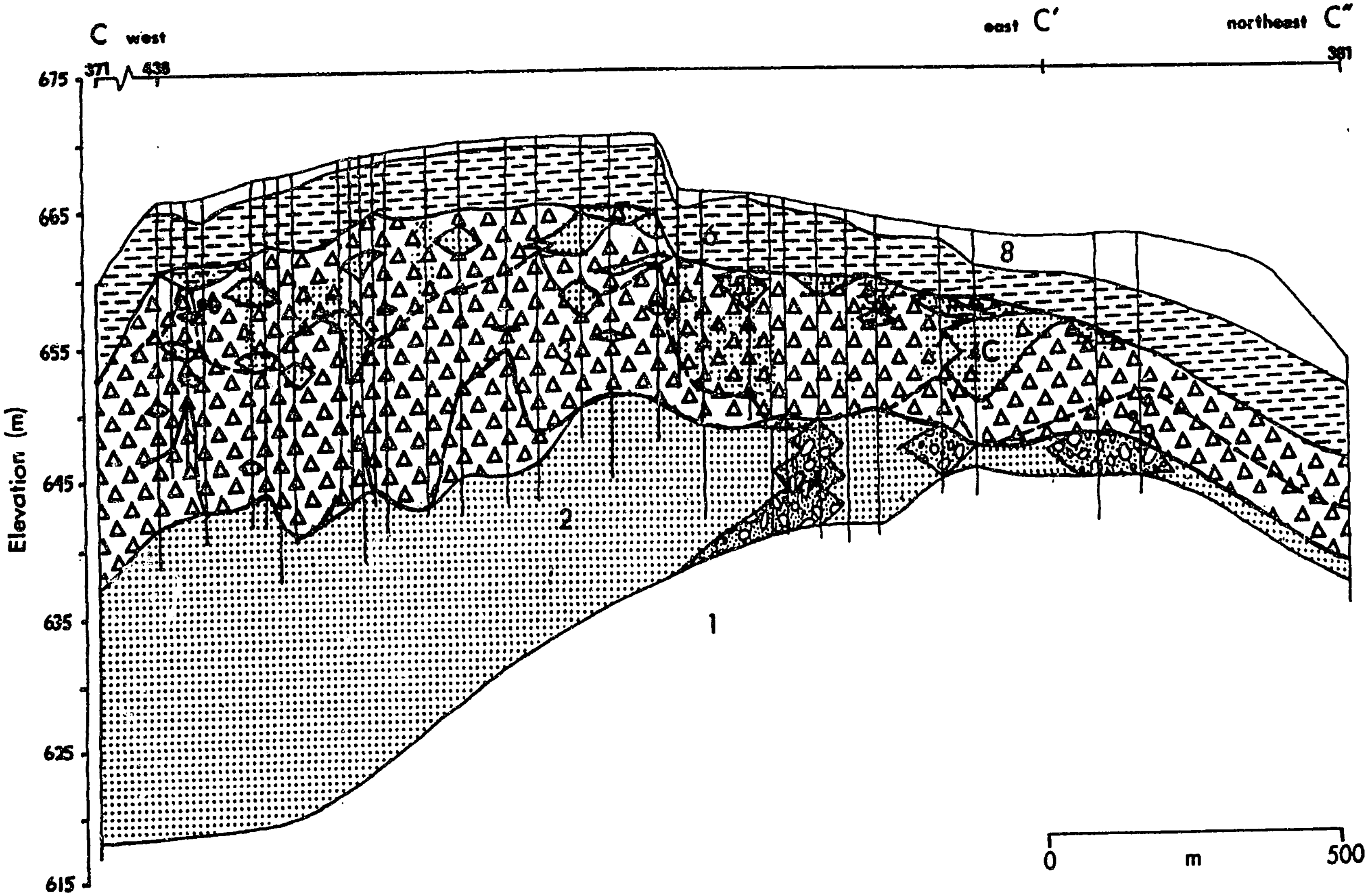


FIG. 5.19. Cross section C. Location on Fig. 5.1, (in pocket). Unit names and symbols in Table 5.5.

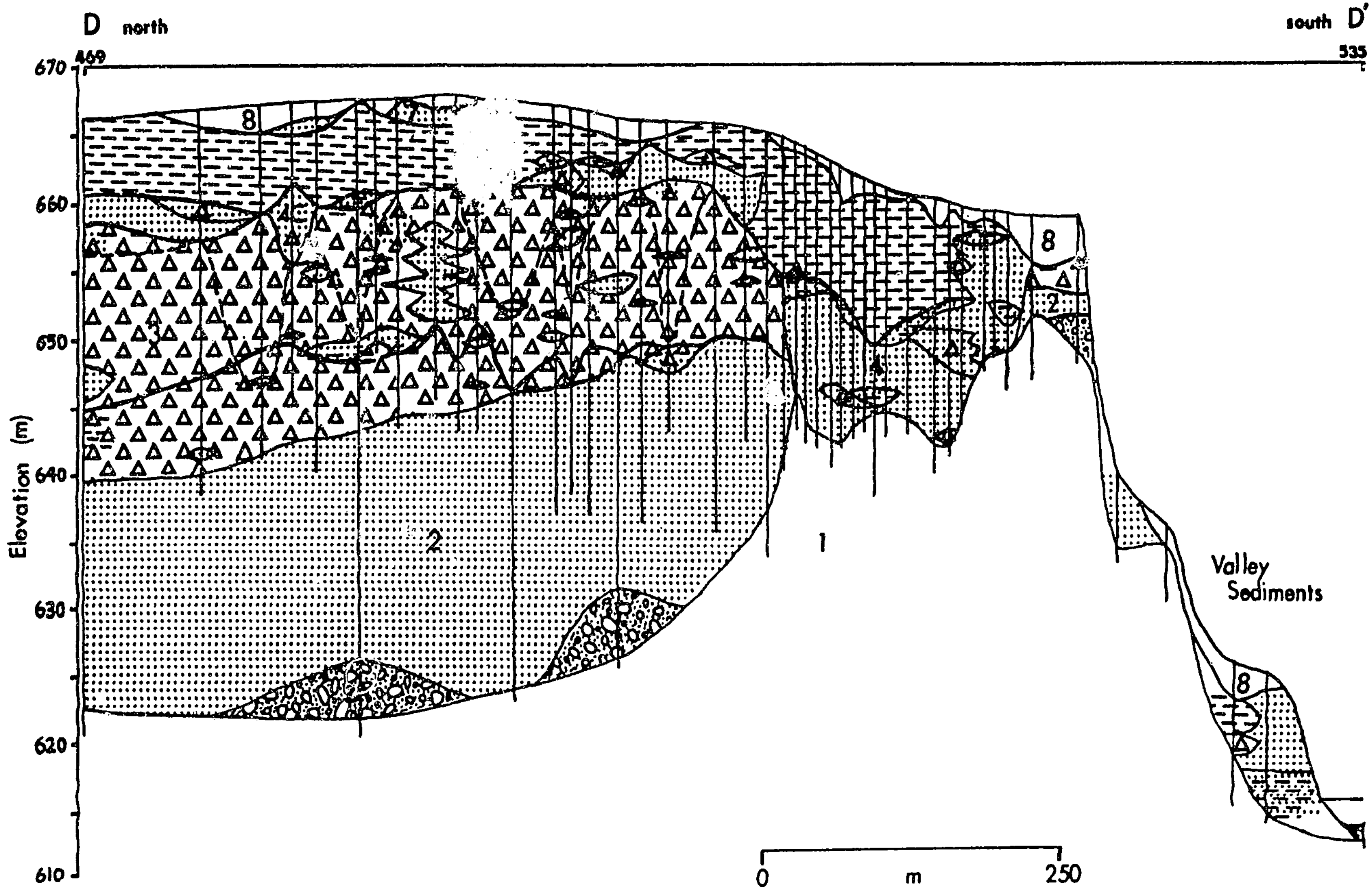


FIG. 5.20. Cross section D. Location on Fig. 5.1, (in pocket). Unit names and symbols in Table 5.5.

the boundary between lower soft clay diamicton and overlying diamicton, is irregular and does not commonly coincide with the highly irregular colour boundary between lower grey diamicton and upper brown diamicton. In the upper part of the complex sand lenses are abundant, but sand diamicton is discontinuous. The colour boundary coincides with the base of sand diamicton in places (sections B and C; Figs. 5.18 and 5.19). Silt diamicton is very localised and uncommon, occurring at the top of the complex (section C; Fig. 5.19). Section C (Fig. 5.19) shows that the diamicton complex is much thicker in the west, over the buried Stony Valley in bedrock, where most of the complex is composed of diamicton containing numerous sand lenses (section D; Fig. 5.20). The thicker complex sediments result in a high in the surface topography. The upper contact of the diamicton complex is very irregular where sand lenses are more common and sand of unit 4 is present. The channel sands of unit 4 (sections A and C; Figs. 5.17 and 5.19) and the numerous sand lenses in the upper part of the complex indicate that in the downtown area much of the complex is probably composed of interbedded diamicton deposited by debris flows and glaciofluvial sand deposited in meltwater channels.

The meltwater channels coalesced in the southwest where meltwater eroded to bedrock (section D, Fig. 5.20). Section D passes through the bedrock channel almost perpendicular to the apparent thalweg, which is aligned northeast-southwest. Unit 4 grades laterally into deposits of unit 5 and 6 (section D, Fig. 5.20), indicating that some of the last meltwater channels existed in the early stages of the proglacial lake.

Unit 7 sand is intersected in sections A and D (Figs. 5.17 and 5.20). The deposits are localised and underlying clay of Unit 6 is not significantly eroded, therefore they must have been deposited in minor channels during or soon after drainage of the proglacial lake.

The North Saskatchewan River in central Edmonton is incised through a bedrock high (sections D and E; Figs. 5.20 and 5.21). Geomorphological features of several types occur in the valley, including erosional terraces, depositional terraces and slumped mounds. In section D (Fig. 5.20) the upper terrace is erosional and contains undisturbed glacial sediments. Lower terraces can contain both Holocene fluvial sediments and material deposited by mass movement from the valley sides. A large bedrock clast in section E (Fig. 5.21) is part of a slumped deposit.

On the south side of the river valley, the units are more laterally variable than on the north side (sections E, F, G, H, I, J, K, and L; Figs. 5.21, 5.22, 5.23, 5.24, 5.25, 5.26, 5.27, and 5.28). Over the bedrock high in the east, sand of unit 2 is gravelly and contains diamicton lenses in places (sections F and K; Figs. 5.22 and 5.27). The overlying diamicton complex is thin, and pinches out laterally where underlying unit 2 appears to grade laterally into sand of unit 4 (section F; Fig. 5.22). The complex consists of stony and sandy diamicton, which

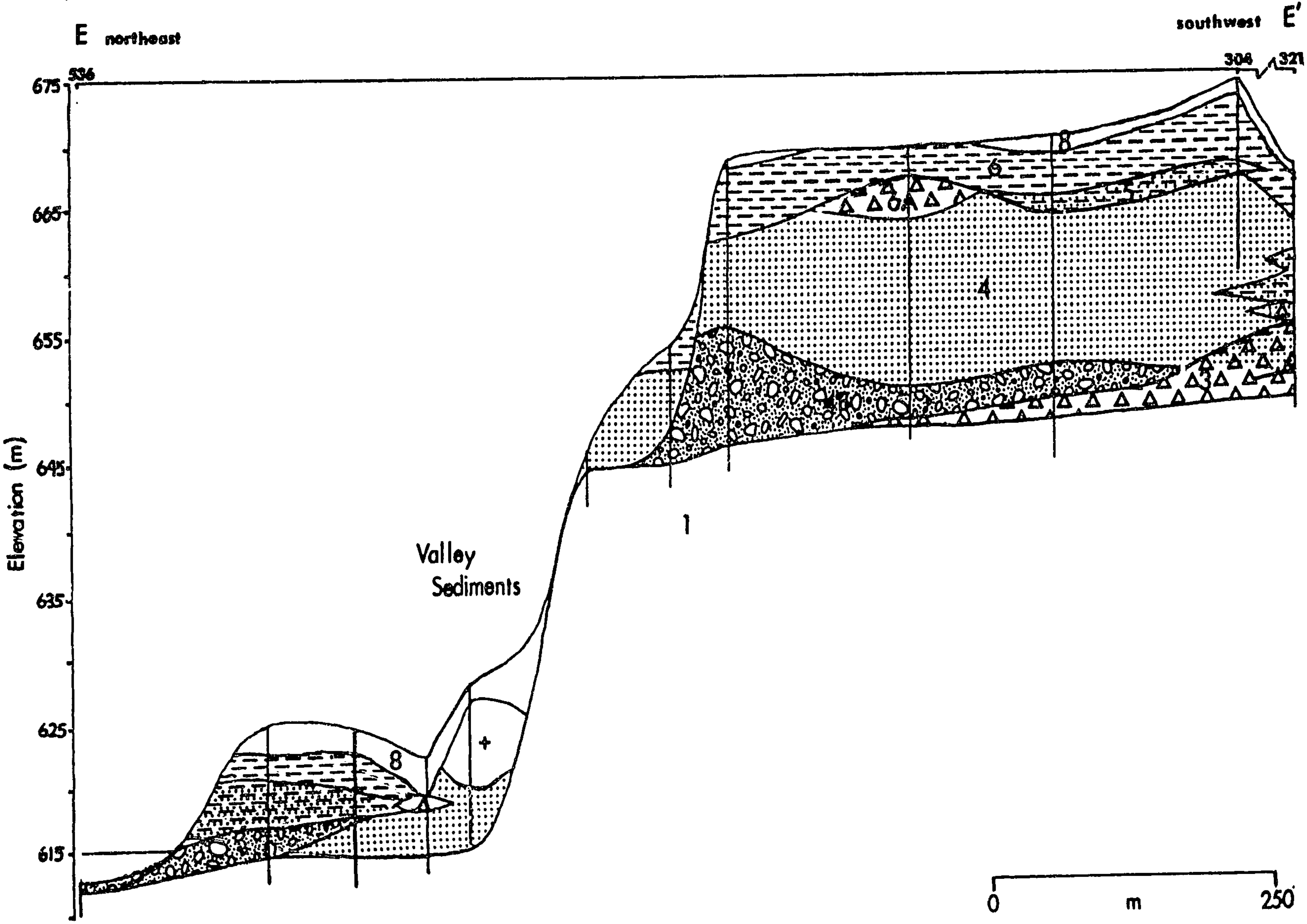


FIG. 5.21. Cross section E. Location on Fig. 5.1, (in pocket). Unit names and symbols in Table 5.5.

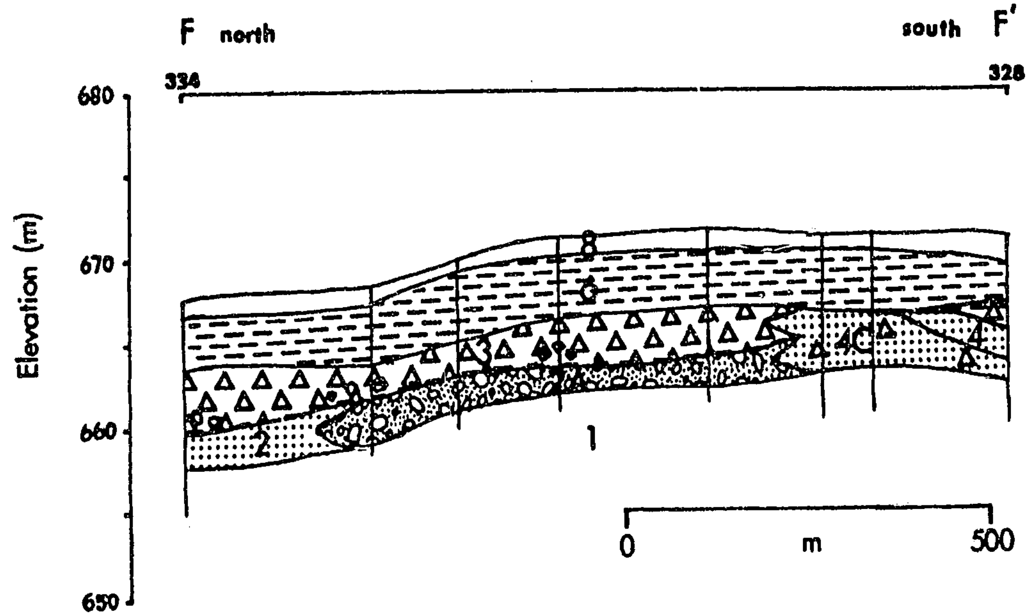


FIG. 5.22. Cross section F. Location on Fig. 5.1, (in pocket). Unit names and symbols in Table 5.5.

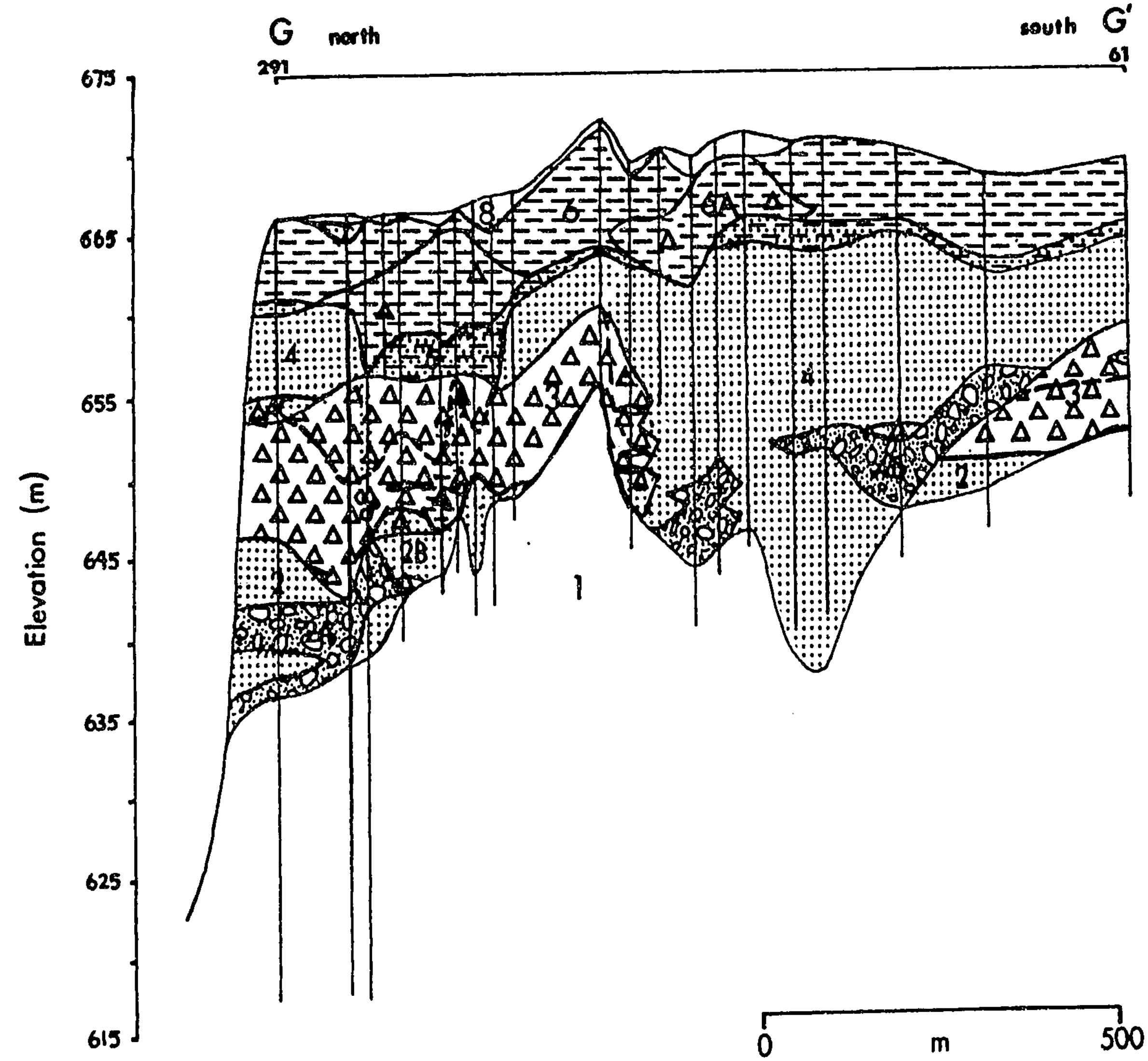


FIG. 5.23. Cross section G. Location on Fig. 5.1, (in pocket). Unit names and symbols in Table 5.5.

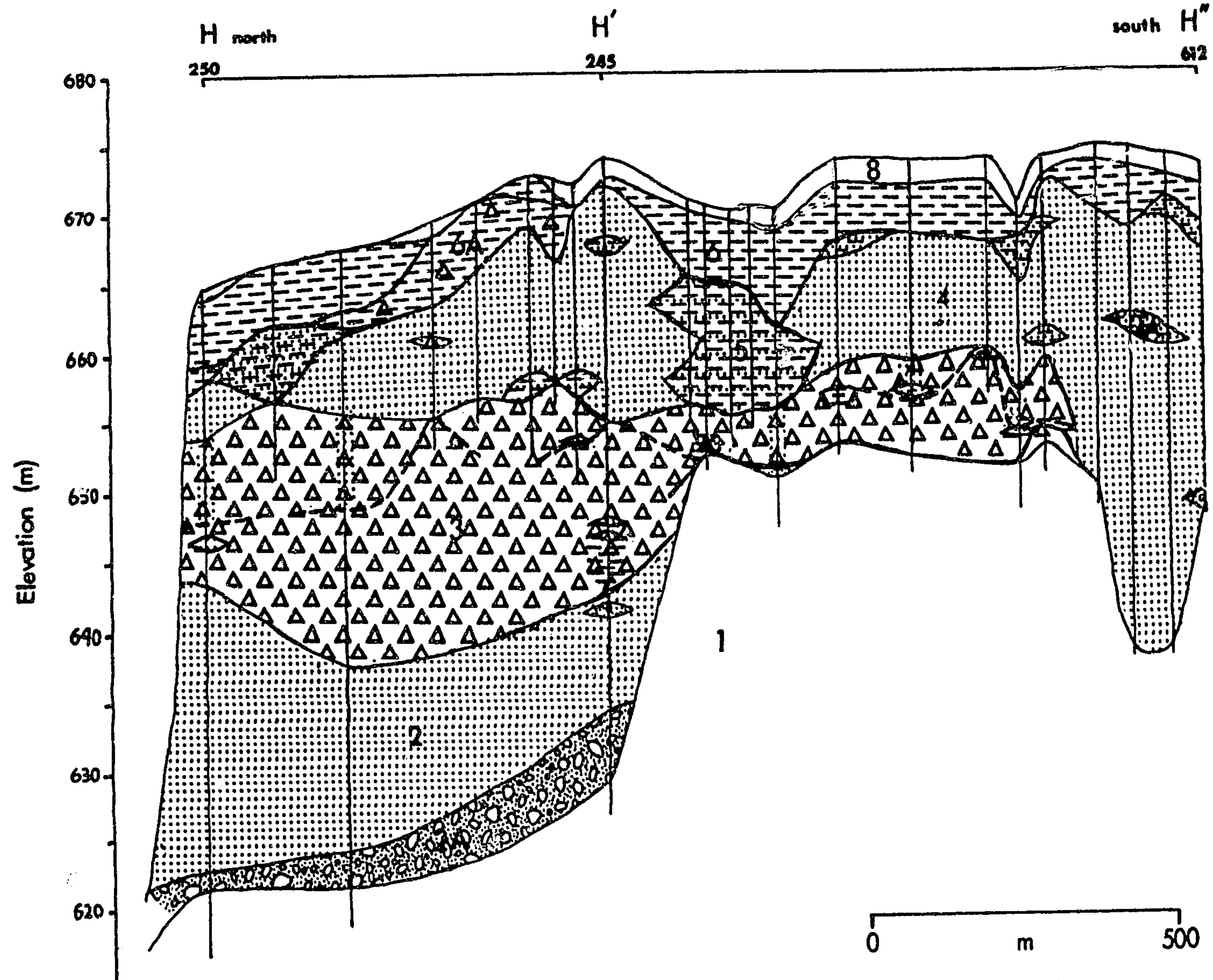


FIG. 5.24. Cross section H. Location on Fig. 5.1, (in pocket). Unit names and symbols in Table 5.5.

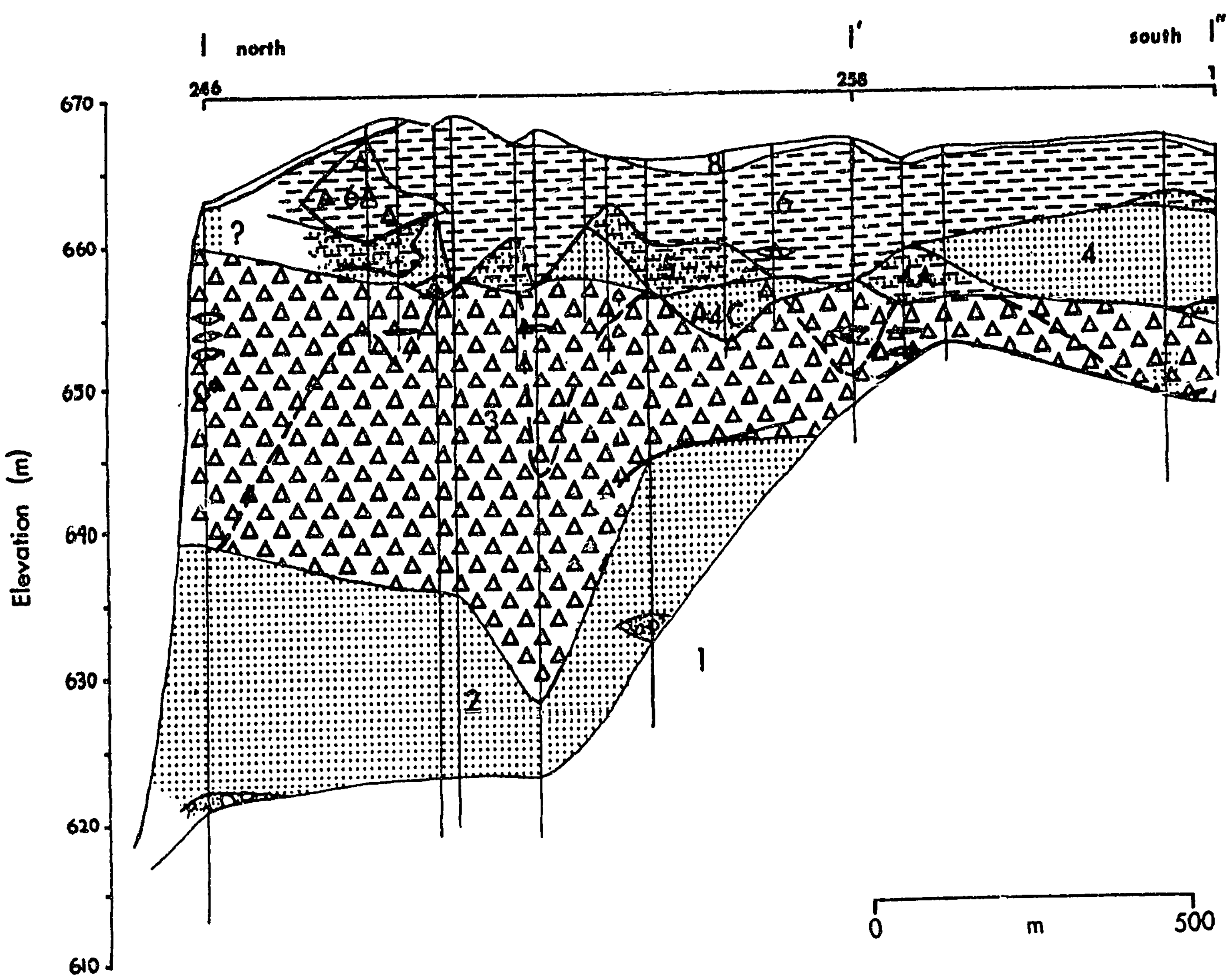


FIG. 5.25. Cross section I. Location on Fig. 5.1, (in pocket). Unit names and symbols in Table 5.5.

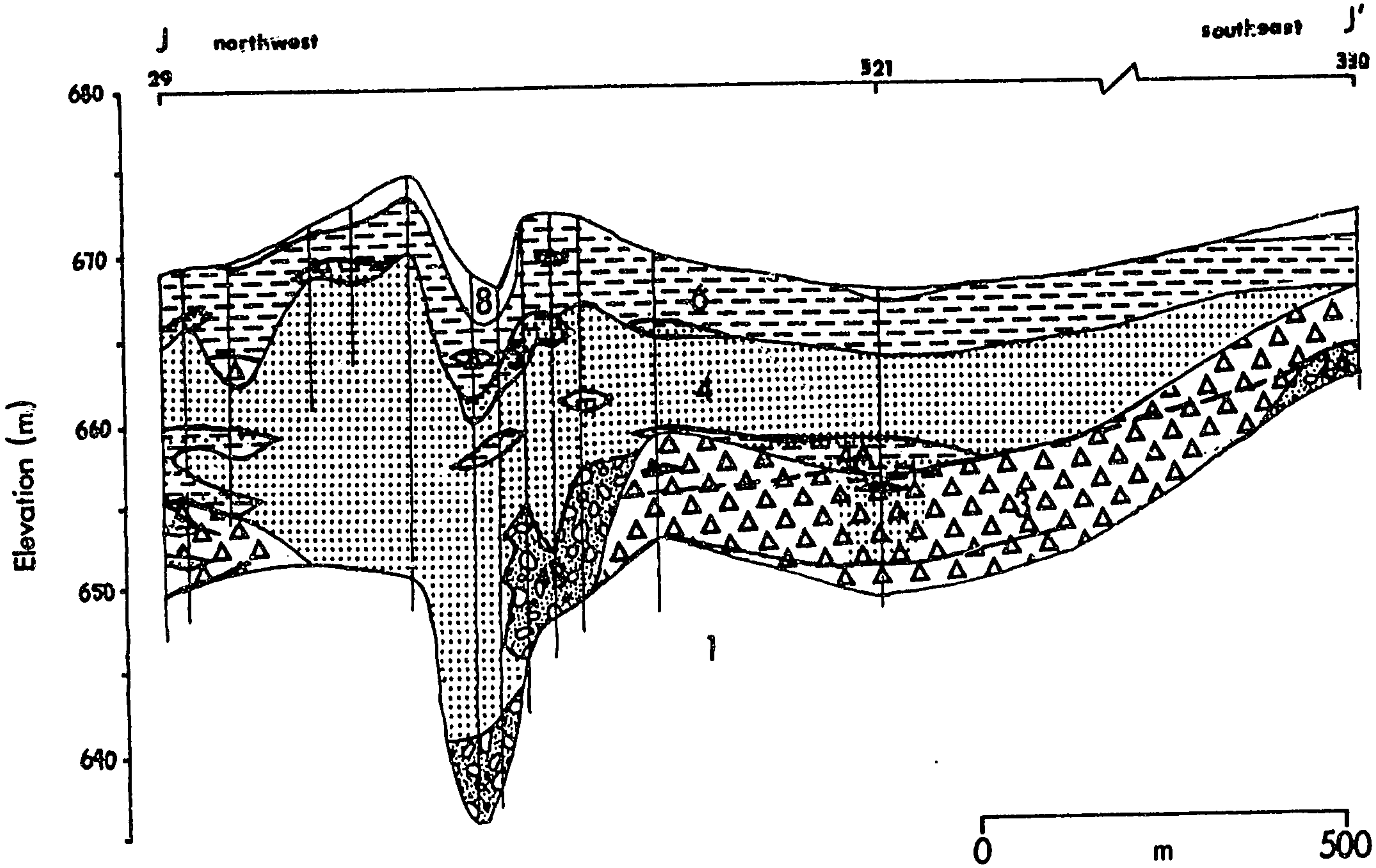


FIG. 5.26. Cross section J. Location on Fig. 5.1, (in pocket). Unit names and symbols in Table 5.5.

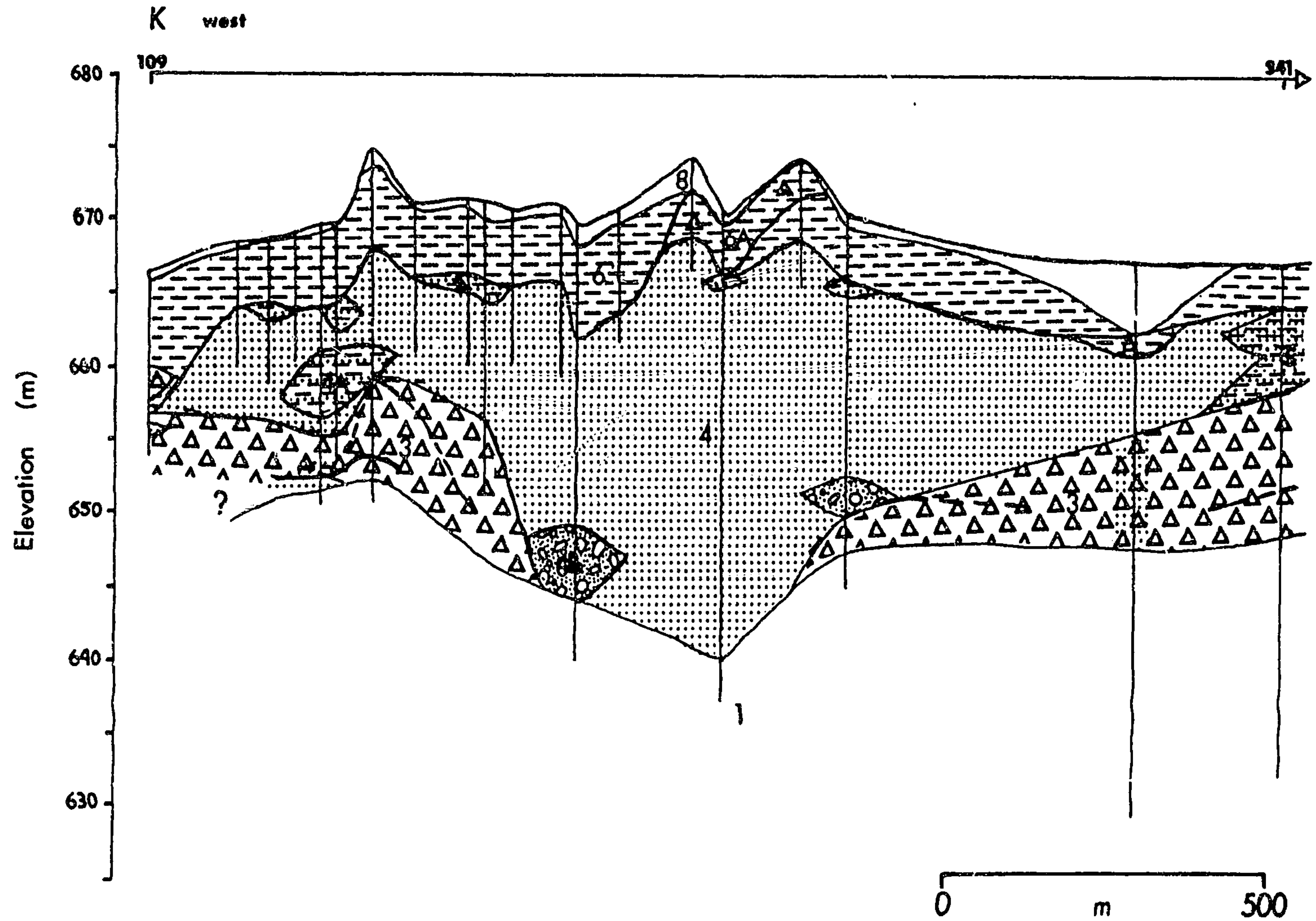


FIG. 5.27a. Cross section K. Location on Fig. 5.1, (in pocket). Unit names and symbols in Table 5.5. Continued on Fig. 5.27b.

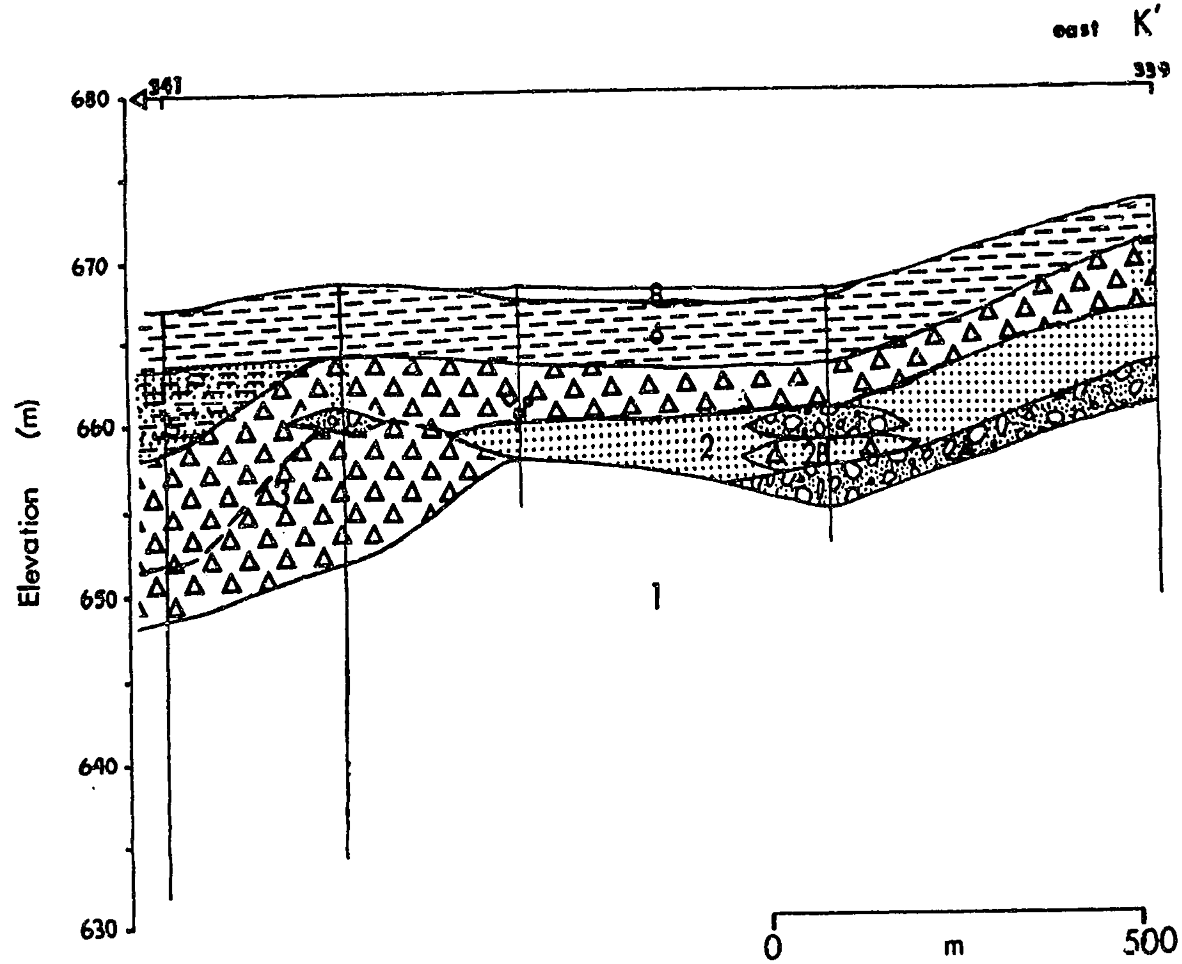


FIG. 5.27b. Continuation of Fig. 5.27a.

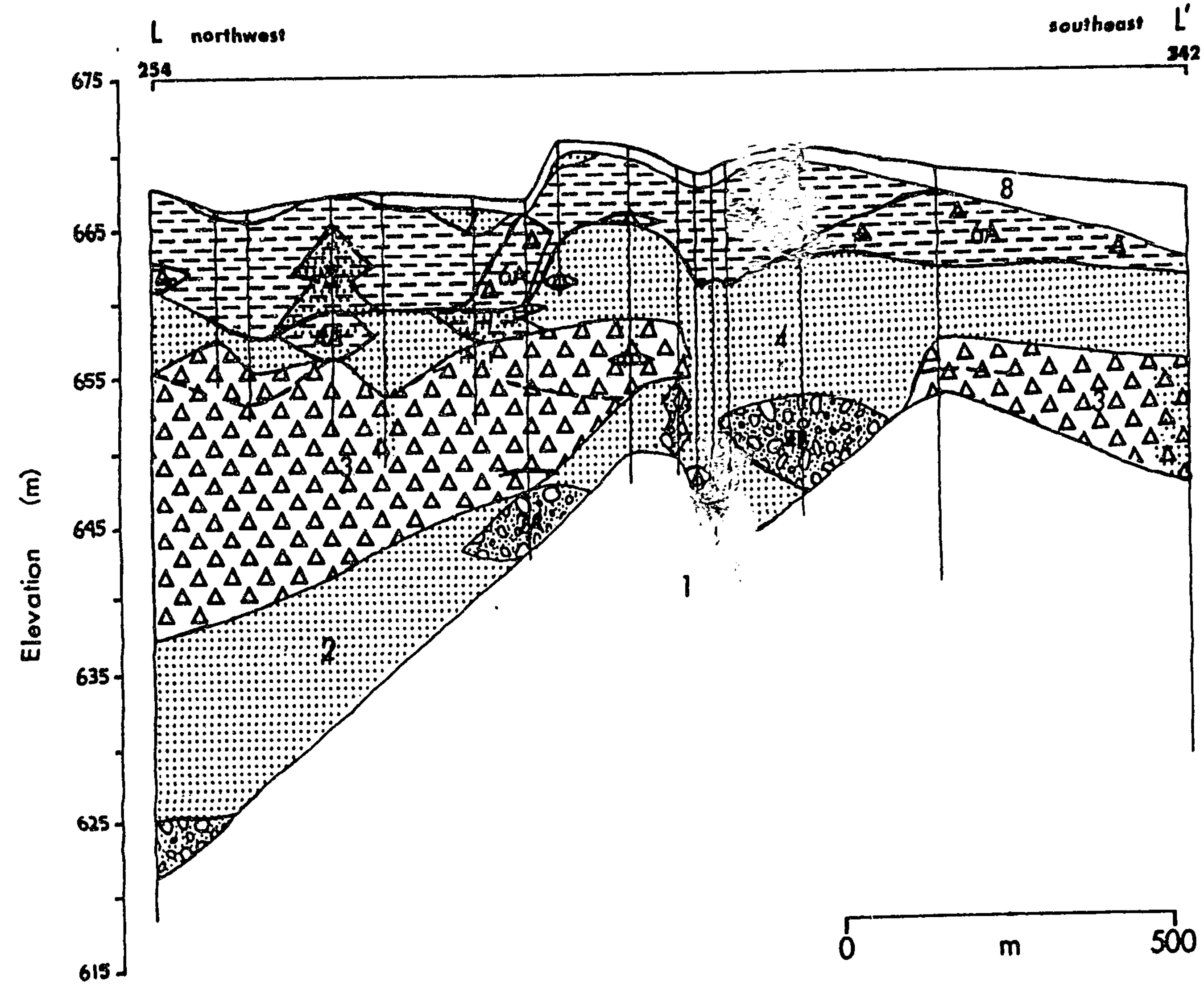


FIG. 5.28. Cross section L. Location on Fig. 5.1, (in pocket). Unit names and symbols in Table 5.5.

grades laterally into the upper part of thicker complex sediments to the west (section K; Fig. 5.27). In this area unit 2, 3, and 4 sediments were probably all deposited during glacial retreat, by meltwater and debris flow processes. Other glacial deposits may have been eroded. Elsewhere over the bedrock high, the diamicton complex is usually in contact with underlying bedrock (sections E, G, H, I, J, K, and L; Figs. 5.21, 5.23, 5.24, 5.25, 5.26, 5.27, and 5.28), suggesting that the glacier sole was in contact with bedrock and subglacial diamictons were probably deposited.

On the south side, the diamicton complex is thickest over the buried Stony Valley in bedrock, in the west (sections H, I, and L; Figs. 5.24, 5.25, and 5.28). The thickness of the complex appears to be influenced mainly by position over bedrock highs and lows. In section I (Fig. 5.25), the lower contact of the complex has a marked low point, and the complex is very thick, near to the wall of the Stony Valley in bedrock. At this location the geometry of the base of the complex may conform to a preglacial fluvial terrace, or the sediments of unit 2 along the valley wall may have been preserved in the lee of a bedrock protuberance situated to the northeast, as the ice moved to the southwest. Generally, the complex does not contain abundant sand lenses but sand and silt diamicton is discontinuous in the upper part (sections G, H, and L; Figs. 5.23, 5.24, and 5.28). The colour boundary between lower grey and upper brown diamicton is irregular but coincides with the base of sandy diamicton in places (section H; Fig. 5.24). Soft clay diamicton at the base of the complex is apparently uncommon, although much less data is available than for the complex on the north side of the river valley. The boundary of soft clay diamicton with overlying diamicton does not coincide with the colour boundary.

The diamicton complex is truncated by glaciofluvial sediments which infill the meltwater channel which incises bedrock. In places the presence of numerous sand lenses in the complex, or interbedded sand and diamicton of unit 4C, suggests a gradational lateral contact between the complex and unit 4 sand (sections E, F, G, and J; Figs. 5.21, 5.22, 5.23, and 5.26). The upper contact of the diamicton complex is also highly irregular where sediments of unit 4 occur. Thus, the complex may grade laterally and upward into unit 4 in places, as the upper complex was probably deposited by meltwater and debris flow processes.

A gravel lag at the base (section J; Fig. 5.26), and at the base and along the side (section E; Fig. 5.21), of the bedrock channel probably represents the first erosional event. Other gravel lags within the channel infill (sections G, H, J, K, and L; Figs. 5.23, 5.24, 5.26, 5.27, and 5.28) indicate there may have been at least two other erosional episodes. Areas of relatively high surface elevation coincide with thick deposits of unit 4, with depressional areas located approximately over the thalweg of the bedrock channel (sections J, K, and L; Figs. 5.26, 5.27, and 5.28). Such a depression may represent the last phase of meltwater flow, after which the channel was infilled by sediments of units 5 and 6.

Silt of unit 5 and sand of unit 4 commonly grade laterally into one another (sections G, H, I and L; Figs. 5.23, 5.24, 5.25 and 5.28).

D. Correlation of Field and Borehole Sediment Units, and Geotechnical Implications

From the field sections, seven sediment units overlying bedrock and not including anthropogenically disturbed material, were identified. From the boreholes, six sediment units overlying bedrock and not including anthropogenically disturbed material, were identified. The units can be correlated by sediment type, geotechnical properties and stratigraphic position. Correlation of the field and borehole units allows interpretation of the depositional environments of the borehole sediment units and discussion of the geotechnical implications of the sediments.

1. Borehole Unit 1 BEDROCK

Correlation

Upper Cretaceous claystone underlying the city of Edmonton is classified in the Horseshoe Canyon Formation of the Edmonton Group, as mapped by Green (1972).

Geotechnical Implications

The upper approximately 1 m of bedrock, which is weak and rubbly or fractured in places on bedrock highs, is generally unsuitable for a foundation surface. Bedrock forming the base of the buried preglacial Stony Valley is located at too great a depth for foundation considerations. High clay contents, Atterberg limits and moisture contents suggests that slope failures would occur in cutbanks. Bentonite beds would be susceptible failure planes.

2. Borehole Unit 2: SAND

Correlation

Sorted sediment overlying bedrock and underlying the diamicton complex is correlative to the combined lower Preglacial Fluvial and the upper Proglacial and Subglacial Fluvial units, interpreted from field sections. The only way to definitely differentiate the preglacial and glacial sediments in the boreholes is by observing whether Shield provenance material is present. In the boreholes, preglacial fluvial sediment containing no Shield material is dominated by well sorted, medium grained sand, and is commonly very dense, with more consistent blow counts than the glacial sediment, that increase with depth. Glaciofluvial sediment containing Shield provenance material is less well sorted, is interbedded with diamicton in places and has a wider range in properties than the preglacial sediments. Crossbedded preglacial sand was probably deposited in braided stream environments, and the deposits are discontinuous, with the thickest infilling buried bedrock channels of the preglacial integrated drainage system. The glacial sediments were deposited in proglacial or subglacial meltwater channels. Diamicton melted out of the ice and flowed into the channels. The deposits are discontinuous and relatively thin. In places over bedrock highs all of the unit consists of glacial sediment.

Geotechnical Implications

Well sorted, medium grained, quartzitic, preglacial sand has a predictable distribution and consistent properties. The sand infills the buried Stony Valley in bedrock and gravel beds along the base and valley sides would be a good source of construction material, except where high percentages of local bedrock lithology occur near bedrock. Depth of the deposits of usually greater than 20 m below the ground surface prevents economically feasible excavation. The consistently high relative density, well sorted nature and thickness of the deposits indicates that the unit would make a good foundation surface. The water table is commonly present in the lower part of the unit so that moisture contents are higher below, however, other properties are consistent throughout the unit. Unit 2 within preglacial valleys could be major local groundwater aquifers.

Moderately to poorly sorted sand and gravel containing Shield material, that was deposited in glaciofluvial proglacial and subglacial channels, is relatively thin where it overlies thick preglacial sediments, therefore it would not affect the generally favourable characteristics of unit 2 for foundation purposes. Over the bedrock high in the south and east of the map area. However, most or all of unit 2 consists of glaciofluvial deposits. Sediment deposited by meltwater proximal to the ice can be highly variable in nature and contain discontinuous lenses of dimaicton. The variable properties of the sediments, the presence of igneous and metamorphic lithologies, and the discontinuous nature and relatively small volume of the deposits, may not make them an attractive source for construction materials, although they are commonly located within 5 m of the ground surface over the bedrock high. The relative density of the glaciofluvial sediments is usually less than that of the preglacial sediments, therefore they would make a less satisfactory bearing surface.

3. Borehole Unit 3: DIAMICTON COMPLEX

Correlation

The diamicton complex, composed of several diamicton types, is correlative to a complex composed of three diamictons interpreted as Till 1, Till 2, and Flowed and Resedimented Diamicton, from field sections.

Lowermost soft clay diamicton is correlative to Till 1. They both have a similar dark grey colour and are located at the base of the complex. Their clay content is higher, relative density lower, moisture content higher and Atterberg limits higher (Figs. 5.29 and 5.30; Tables 4.2 and 5.4), than the other diamictons. The high clay content and high Atterberg limits of the borehole unit is best matched by the properties of the clay lens within Till 1.

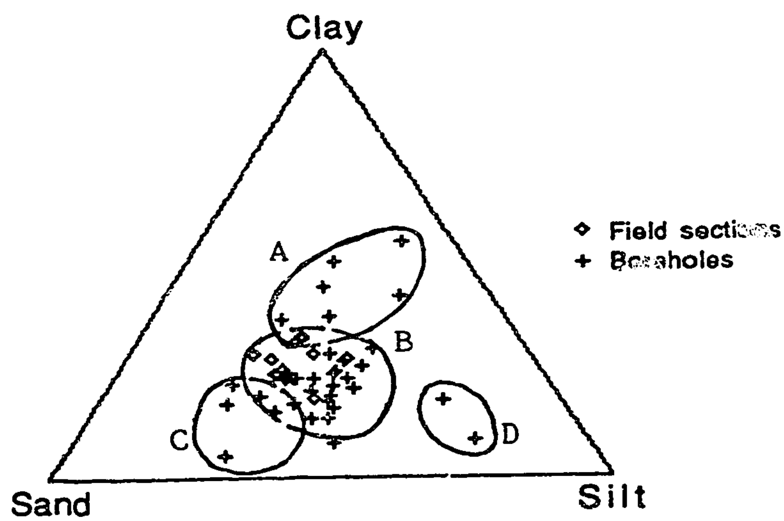


FIG. 5.29. Matrix grain size distributions for glacigenic diamictons in Edmonton. Envelopes: A, Till 1; B, Till 2; C, sand flow diamicton; D, silt flow and resedimented diamicton.

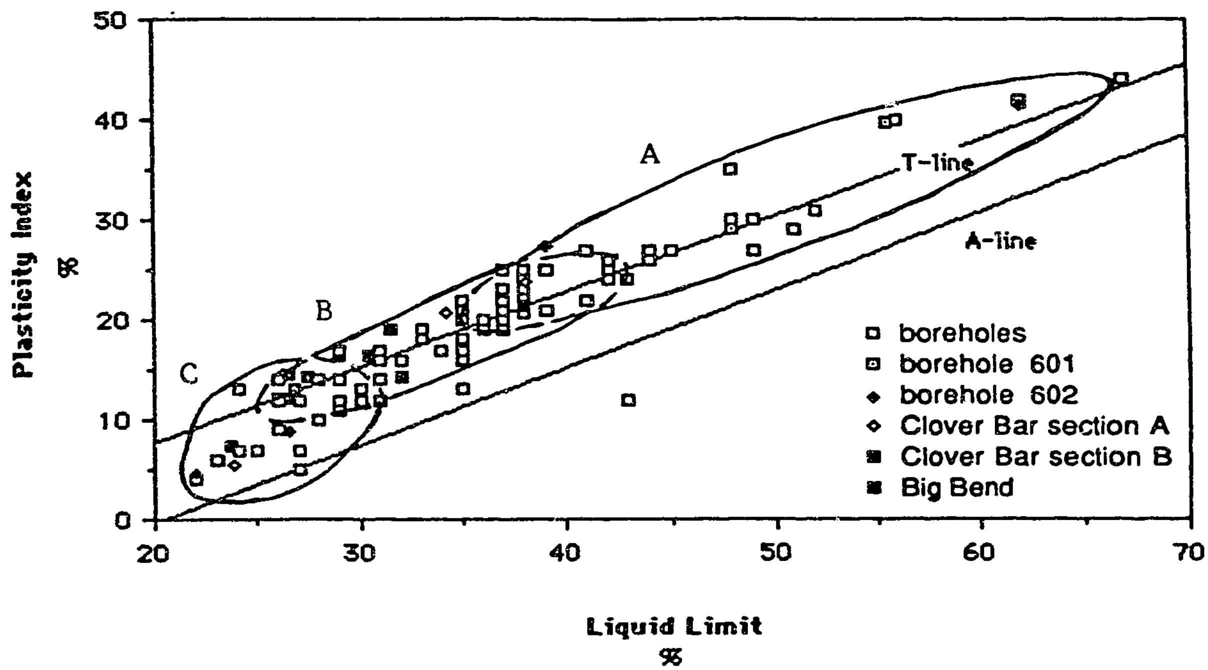


FIG. 5.30. Atterberg limits for glacigenic diamictons in Edmonton. Envelopes: A, Till 1; B, Till 2; C, sand and silt flow and resedimented diamicton.

The diamicton was deposited as subglacial till, probably by melt out or debris flow into isolated subglacial cavities, beneath an advance lobe of the last glaciation moving toward the southeast. The high clay content is probably due to incorporation of lacustrine deposits. Disturbance of the diamicton by overridding ice, indicated by the highly fractured nature, the load features, and fold features to the west, may have destroyed structure of lodgement origin, however, the presence of a preserved clay lens within the diamicton suggests a melt out origin. The bimodal fabric transverse and parallel to ice movement direction may be a melt out fabric, or the northeast-southwest component may have been introduced by overridding ice. Till 1 has a patchy distribution and irregular thicknesses. In central Edmonton it is more common on the north side of the river valley, where the complex is thick over the buried Stony Valley.

Sand diamicton occurring in places at the base of the complex or directly overlying the contact with Till 1, may be correlative to a lowermost sandy unit of Till 2. The sandy texture is likely from incorporation of substrate material. Sand diamicton of Till 2 is relatively thin, localised and is not common in central Edmonton. The clay-silt-sand diamicton is broadly correlative to Till 2, although it may grade up into flow diamicton. There are only localised areas where Till 2 is absent, over the bedrock high in the southeast where the complex appears to be entirely composed of flow diamicton in places. The melt-out till tends to have a slightly higher clay content than the flow diamicton (Fig. 5.29). The relative density is high. Atterberg limits are low relative to the other diamictons (Fig. 5.30). The pebble fabric is strong, with a northeast-southwest orientation parallel to regional ice movement direction. Till 2 was deposited subglacially, probably by melt out beneath the main body of the last glacier. It has a lodgement component along the erosional base. Abundant sand lenses are present within the unit.

Sand and silt diamictons occurring in the uppermost part of the complex are correlative to Flow and Resedimented Diamicton. The means of correlation are stratigraphic position and sedimentary association. In the boreholes sand and silt diamictons are intimately associated with a concentration of sand and silt lenses in the upper part of the complex. Flow Diamicton interpreted in the field contains lenses of sorted sediment which are more silty toward the top of the complex. It is interbedded with thin beds of silty clay at the top of the unit, and grades up into glaciofluvial and glaciolacustrine sediment. Texture and Atterberg limits are variable and cannot be absolutely distinguished from sediments of Till 2 (Figs. 5.29, and 5.30), except for some flow units which have significantly higher coarse clast contents (Tables 4.1 and 4.2). Flow diamicton is widespread, but the thickness is highly variable and it is discontinuous. Over bedrock highs, where the diamicton complex is relatively thin, flow diamicton composes the entire complex in places where the complex does not directly overlie bedrock but is underlain by discontinuous glaciofluvial deposits of unit 2. Flow diamicton was deposited in the retreat phase of the glacier and is interbedded with, and grades laterally into, glaciofluvial sediment deposited in meltwater channels debouching from the ice margin. The source of the diamicton was the ice margin which became grounded in a proglacial lake, so that many of the flows were subaqueously deposited and interbedded with glaciolacustrine sediment. Flow diamicton is sparsely represented where large deposits of glaciofluvial sand infill a meltwater channel eroded into bedrock in the central and southern parts of the city.

Geotechnical Implications

The diamicton complex is generally continuous and thick in the area mapped and its intermediate stratigraphic position in the Quaternary sequence makes it important to the location of deep foundations and tunnels within the city. The complex is not uniform throughout, and no continuous interdiamicton unit of sorted sediment exists. Discontinuities in the form of different textural types of diamicton and lenses of sorted sediment are common.

Soft clay diamicton which occurs discontinuously at the base of the complex is the least overconsolidated diamicton and provides the least desireable foundation conditions. Fractures contribute to its weaker condition.

The bulk of the complex, consisting of subglacial clay-silt-sand till and sand flow diamicton, is largely highly overconsolidated due to dessication, and provides good foundation conditions. However, sand lenses are concentrated in the upper part of the complex and are commonly saturated so that they could cause seepage problems. Columnar dessication jointing in the upper complex could cause block failures. The middle and lower parts of the complex, above clay diamicton, would offer the least problems for tunnelling, especially where the diamicton complex is thick due to a greater component of flow diamicton and sand lenses deposited in ridges. In places perched water tables over the complex result in moist and weaker conditions in the uppermost approximately 1 m. In addition, sporadic soft zones occur in silt and sand diamicton at the top of the complex. In summary, the top and bottom parts of the complex are generally less suitable for engineering purposes.

4. Borehole Unit 4: SAND

Correlation

Sand overlying bedrock or the diamicton complex and grading up into silt and clay is correlative to Outwash and Early Proglacial Lake sediment. As the ice melted and retreated in the Edmonton area, large amounts of meltwater deposited thick sequences of sorted sediment. Concentration of initial high discharge meltwaters in central Edmonton eroded underlying sediment to bedrock in a channel and deposited gravel lags. As the amount of meltwater decreased and proglacial lakes formed, sediments became finer grained. Most of the unit was probably deposited in subaqueous fans building out from the glacier margin, which create highs in the surficial topography. Where has a lower relative density than preglacial sand. Interbedded diamicton beds are flow diamicton originating from the ice margin or preexisting till deposits. The sand is regionally not widespread, but is common in central Edmonton. Over the diamicton complex the unit is discontinuous and grades laterally into diamicton containing abundant sand lenses. This area must have been a zone of high meltwater discharge from the ice margin.

Geotechnical Implications

Glacial outwash sand has more variable sediment types and properties than sand of unit 2. It has lower average relative density, however, it is not saturated and forms thick deposits in places, therefore it would make a satisfactory bearing surface. Zones of highly variable sediment types containing flow diamictons would be relatively unsuitable for foundation purposes. Where lacks diamicton interbeds, the unit could provide a local source of fill or construction material. It is accessible for excavation, as the top of the unit commonly occurs within 5 m of the ground surface. Sand infilling bedrock meltwater channels could be a good local aquifer, especially where the confining upper walls are formed by the diamicton complex directly overlying bedrock.

5. Borehole Unit 5: SILT

Correlation

Silt underlying and grading up into clay is correlative to Outwash and Early Proglacial Lake sediment. Silt beds are massive and crossbedded and were probably deposited by turbidity flow and underflow in the proglacial lake. As sediment supply diminished and the lake deepened the silt graded up into laminated lake clays and silty clays. The silt beds in central Edmonton are localised, but elsewhere can comprise thick sequences (Big Bend).

Geotechnical Implications

Glaciofluvial and glaciolacustrine silt is commonly too thin and discontinuous to provide a consistent bearing surface, and would be weaker than undelrying glaciofluvial sand or the overconsolidated diamicton complex, especially where saturated due to a perched table above the diamicton complex.

6. Borehole Unit 6: CLAY

Correlation

Clay, interbedded with silt and sand and containing diamicton lenses, is correlative to Proglacial Lake sediments. The sediments are in places rhythmically bedded, medium to high plastic, laminated clay and silty clay, disturbed in places, and containing dropstones and diamicton lenses melted out of floating ice. The deposits have a blanket distribution, with some interruptions where they grade laterally into coarser, glaciofluvial sediment.

Geotechnical Implications

This unit occurs everywhere outside of the river valley in the area mapped, and is therefore important to shallow foundations and road construction. The properties of the glaciolacustrine clay vary vertically so that the middle of the unit has the highest moisture content, clay content and Atterberg limits. The upper approximately 1 m is weathered, dessicated and fractured and is therefore weaker. The lower part of the unit is commonly silty, and diamicton lenses occur at the base. Foundation settlement and heaving problems and slope failures in cutbanks, are very likely in this unit. If the unit is thick and unavoidable for shallow foundations, the lowermost part would be the most suitable foundation level, especially if the clay contains sand interbeds or overlies sand of unit 4, which could provide drainage.

7. Borehole Unit 7: SAND

Correlation

This unit does not have a correlative unit in the field sections. It was probably deposited in minor fluvial channels soon after drainage of the proglacial lake. It is very localised in distribution.

Geotechnical Implications

The minor extent and thinness of unit 7 makes it an insignificant deposit for most site investigations, except as a local source of fill.

CHAPTER VI
SUMMARY

A. Conclusions

1. The stratigraphy of Quaternary sediments overlying Upper Cretaceous sedimentary bedrock in central Edmonton consists of preglacial fluvial sand with some gravel beds, glaciofluvial sand and gravel with some lenses or beds of diamicton, a diamicton complex composed of two subglacial tills and flow diamictons, glaciofluvial sand with some gravel, silt and diamicton beds, glaciolacustrine silt, glaciolacustrine clay with some diamicton beds, and postglacial sand.

2. Glacigenic sediments in central Edmonton were deposited during one major glaciation in the Late Wisconsinan.

3. The distribution of Quaternary sediments in central Edmonton is largely controlled by the bedrock topography. Thick deposits of preglacial sand infill the Stony Valley, which is incised into bedrock. Glaciofluvial sediments discontinuously overlie the preglacial deposits or bedrock on bedrock highs. The diamicton complex is generally continuous and is thinner over bedrock highs and thicker over the Stony Valley. Clay till occurs discontinuously at the base of the complex. Most of the complex is composed of clay-silt-sand till which grades vertically and

laterally into upper sand flow diamicton. The complex is locally thicker and contains more sand lenses where the flow diamicton component is greater. Outwash sand is continuous within a linear meltwater channel which was cut through the diamicton complex and incises bedrock. Interbedded outwash, flow diamicton and glaciolacustrine sediments form a broad ridge over the meltwater channel. Fine grained glaciolacustrine deposits blanket the area, vary the least in thickness and are thickest over the Stony Valley. Postglacial fluvial sand occurs in small deposits adjacent to the modern North Saskatchewan River valley.

4. The glacigenic diamicton complex in central Edmonton has an intermediate stratigraphic position within the Quaternary sequence, has a widespread distribution with an average thickness of about 10 m and a maximum thickness of about 30 m, and is therefore an important unit to the construction of tunnels and deep foundations. It consists of several diamictons. The general stratigraphy within the complex is a discontinuous, lowermost, soft, clay diamicton, subglacially deposited and disturbed, but not eroded, by overriding ice, overlain by clay-silt-sand diamicton, which is predominantly melt-out till, overlain by sand diamicton containing numerous sand lenses, which is predominantly flow diamicton, overlain by localised deposits of silt diamicton at the top of the complex, which are subqueously deposited resedimented or flow diamictons. Meltout till grades vertically and laterally into flow

diamicton. Sand lenses occur throughout the complex, and no continuous interdiamicton stratum of sorted sediment exists. Superimposed on the complex are the effects of oxidation, causing an upward gradational colour change from grey to brown, and dessication, which has formed a highly overconsolidated crust of variable thickness in the upper part of the complex. The middle and lower parts of the complex, above soft diamicton and below concentrations of sand lenses, is most consistent in its properties for engineering purposes. The highly overconsolidated upper complex generally would provide a good bearing surface for structures. Stony horizons throughout the complex might be difficult to excavate.

5. The properties of diamictons useful in correlating between field sections and boreholes include stratigraphic position, matrix texture, Atterberg limits, moisture content and relative density. Two general units can be correlated regionally. One unit is a discontinuous, commonly darker, lower, soft, clay diamicton with higher moisture contents and Atterberg limits, especially where it contains lenses of clay. The other unit is a continuous, upper, highly overconsolidated unit consisting of both clay-silt-sand and sand diamicton which grade into one another, with lower moisture contents and Atterberg limits and containing abundant sand lenses in the upper part.

6. Glacial outwash sand and glaciolacustrine silt and clay

above the diamicton complex can contain lenses or beds of diamicton. These diamictons, deposited by debris flow, generally average about 1 m in thickness, are laterally discontinuous, silty, interbedded with, or contain lenses of, sorted sediment and have higher moisture contents and lower relative density than diamictons of the upper part of the diamicton complex. It is important to distinguish these diamictons from the diamicton complex as they would make a less satisfactory bearing surface.

7. Detection and mapping of significant meltwater features such as the buried meltwater channel which incises bedrock on the bedrock high and extends for at least several kilometres, is important for tunnelling projects. Channel sediments may also provide a local source of construction material or have aquifer potential. Surface indication of such deposits are ridges trending approximately parallel to ice movement directon.

B. Future Work

The validity of correlating between field and borehole sediments in Edmonton should be tested by drilling holes adjacent to sections or working in excavations close to boreholes, and characterising the units by their geotechnical properties and analysing the consistency of the data.

Additional drilling information would refine the unit distributions for central Edmonton. It should be encouraged to drill as many holes as possible to bedrock, especially in areas where little data is presently available, such as in the northwestern and southeastern parts of this study. Future drilling south and southwest of the study area could determine the southern extent of the bedrock meltwater channel and allow a complete model of its depositional environment to be made. Adoption of a standardised, descriptive (non-genetic) terminology for borehole sediment units, such as that used in this study, would allow more accurate identification, correlation and interpretation of sediments. Abundant sampling and concentrated sampling at unit contacts, would produce more accurate and detailed unit descriptions. Observations of the sediment type, structure and bedding, nature of unit contacts and properties of sediment should be made as detailed as possible in the field. Electric logs would provide stratigraphic information because the logs are continuous and detect minor beds and lenses (cf. Sauer 1974). Lithologic analysis of all samples of sorted sediment overlying bedrock and underlying the diamicton complex would allow the actual thicknesses and distributions of preglacial versus glacial sand and gravel deposits to be mapped.

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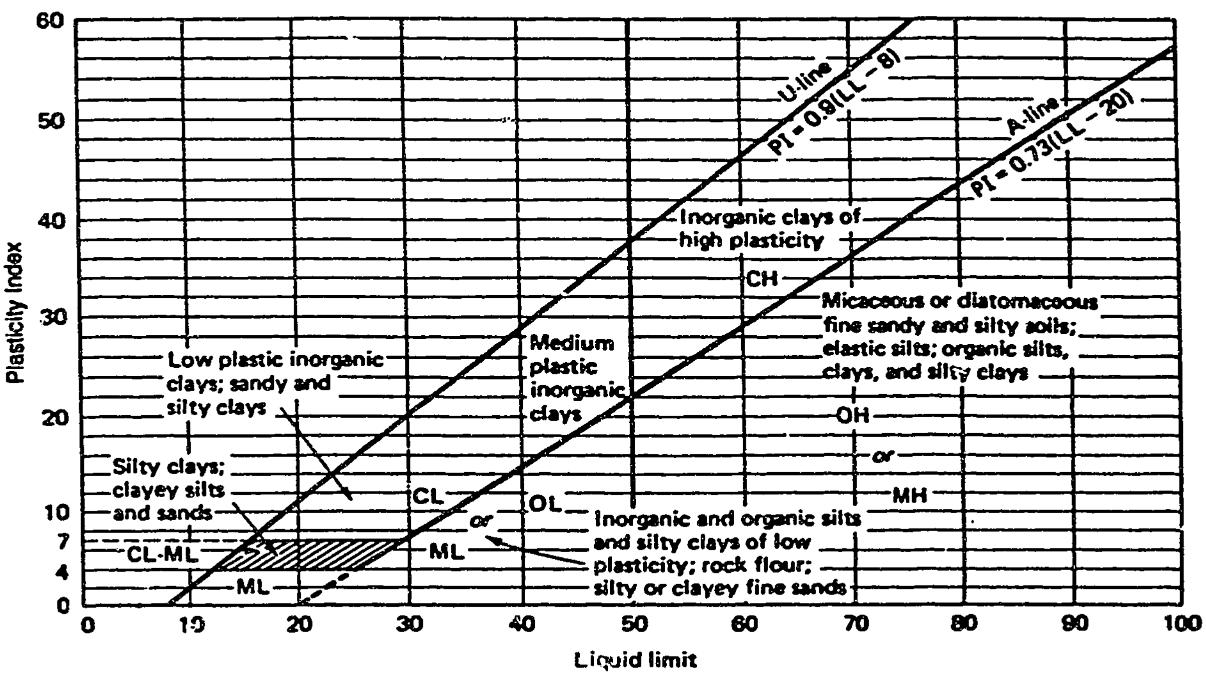
Appendix A

FIG. 1. Casagrande's Plasticity Chart. Developed from Casagrande 1948, and Howard 1977.



Major Divisions (1)	Major Divisions (2)		Group Symbols (1) (3)	Typical Names (4)	Field Identification Procedures (excluding particles larger than 75 mm and basing fractions on estimated weights) (5)	Laboratory Classification Criteria (6)
Coarse grained Soils: More than half of material is larger than No. 200 (1) (75 µm) sieve size.	Gravels: More than half of coarse fraction is larger than No. 4 sieve size (4.75 mm)	Clean Gravels (little or no fines)	GW	Well graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3 (See Sec. 2-8)
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.	Not meeting all gradation requirements for GW
		Gravels with Fines (appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below)	Atterberg limits below A-line, or PI less than 4. Above A-line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).	Atterberg limits above A-line with PI greater than 7
	Sands: More than half of coarse fraction is smaller than No. 4 sieve size (4.75 mm). (For visual classification, 5 mm may be used as equivalent to the No. 4 sieve size)	Clean Sands (little or no fines)	SW	Well graded sands, gravelly sands, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.	$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3 (See Sec. 2-8)
			SP	Poorly graded sands, gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.	Not meeting all gradation requirements for SW
		Sands with Fines (appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below)	Atterberg limits below A-line, or PI less than 4. Limits plotting in hatched zone with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).	Atterberg limits above A-line with PI greater than 7

The No. 200 sieve size is about the smallest particle visible to the naked eye.

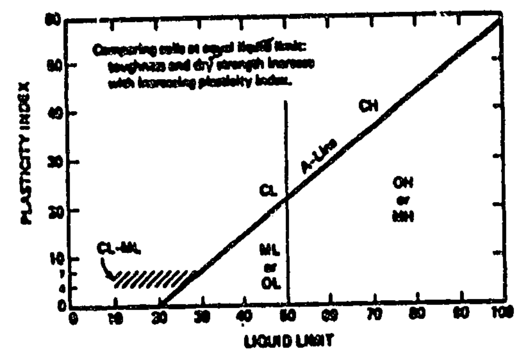
Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows: Less than 5%: GW, GP, SW, SP. More than 12%: GM, GC, SM, SC. 5% to 12%: Borderline cases requiring use of dual symbols.

Use grain size curve in identifying the fractions as given under field identification.

Identification Procedures on Fraction Smaller than No. 40 Sieve Size:

Major Divisions (1)	Major Divisions (2)	Group Symbols (3)	Typical Names (4)	Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near PL)
Fine grained Soils: More than half of material is smaller than No. 200 (75 µm) sieve size.	Silts and Clays: Liquid limit less than 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium
		OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight
	Silts and Clays: Liquid limit greater than 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium
		CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High
		OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium
Highly Organic Soils		Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture.		

Plasticity Chart
For laboratory classification of fine-grained soils



(1) Boundary classifications: soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well-graded gravel sand mixture with clay binder.

Appendix A

TABLE 1. Unified Soil Classification System. After U.S. Army Engineer Waterways Experiment Station (1960) and Howard (1977). CI, as used in thesis, represents clays of medium or intermediate plasticity.

Appendix A

TABLE 2. Moisture scale used in describing sediments in the field.

	Approximate Moisture Content of Sediment (%)
Dry	< 5
Moist	5 - 20

TABLE 3. Hardness scale used in describing cohesive sediments in the field.

	Pocket Penetrometer Resistance (kPa)
Soft	<250
Firm to Stiff	250 - 480
Hard	>480

Appendix B
Borehole Reference List

Hole No.	University Soil Report Index No.	Report Title, Contractor, Year
1-18	SR84	University of Alberta Hospital (various, 1954-67)
19-22	SR45	South Power Plant (Materials Testing Lab, 1957)
23-26	SR28	Lister Hall and Residences (Hardy, 1961
27-28	SR31	Nurses Residence (Hardy, 1955)
29-31	SR57	University Services (Bernard & Hoggan, 1973)
32	SR58	South Power Plant Stack (Hoggan, 1975)
33-36	SR94	Auditorium Service Tunnel (Brooker, 1973)
37-45	SR141	Proposed Services Corridor 8 (Brooker, 1981)
46-47	SR71	South Power Plant (Hoggan, 1975)
48	SR150	Rehabilitation Medicine Trailers (Thurber, 1986)
49-58	SR73	U of A Hospital parkade (Hoggan, 1981)
59-69	SR50	Trunk Sewer phase 2 (Hoggan, 1967)
70-71	SR51	Trunk Sewer phase IV (Hoggan, 1969)
72-74	SR60	Services Tunnel phase VII (EBA, 1975)
75	SR75	Services Corridor Phase VII A (EBA, 1978)
76-86	SR84	U of A Hospital (various, 1954-67)
87-96	SR93	Services Tunnel Phase V (Brooker, 1973)
97-103	SR5	Proposed Medical Science (Bernard & Hoggan, 1969)
104-108	SR41	Tunnel Services Phase II (Brooker, 1969)
109-110	SR52	University Stadium (Bernard & Hoggan, 1964)
111-119	SR33	Phys. Ed. and Rec. (Materials Testing, 1958)
120-124	SR34	Addition to Phys. Ed. and Rec. (Hardy, 1963)
125-127	SR62	Physical Ed. (Bernard & Hoggan, 1968)
128-130	SR21	Education Centre I (Hardy, 1961)
131-137	SR22	New Education Centre Phase I (Brooker, 1970)
138	SR26	Household Economics I (Bernard & Hoggan, 1963)
139-141	SR65	House Economics Phase I,(Bernard & Hoggan, 1972)
142-144	SR23	Fine Arts (Brooker, 1969)
145-149	SR27	Law (Brooker, 1969)
150	SR155	Temporary Trailers (Thurber, 1986)
151-155	SR68	Services Tunnel East Campus (Hoggan, 1981)
156	SR17	Clinical Services (Materials Testing, 1957)

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Hole No.	Consultant	Report Title, Number, Year
304	Hardy Assoc.	Condominium (B-4062,1977)
305		Queen Alexandra School (E-2418,1972)
306		CP Warehouse (E-2099,1970)
307		Sterling Homes (B-4394,1978)
308		Cascade Apt. (E-2290,1971)
309-313		Sask Dr Apt. (E-1819,1969)
314-318		Underpass (E-3125,1974)
319	EBA Consulting	Wings Food Plant (0106-4246,1985)
320		McDonalds (0106-4138,1984)
321		Garneau Clinic (1979)
322		Sask. Dr. Condos (1-1564,1977)
323		Tipton Arena (E-413,1972)
324		87 Ave Overpass (E-157,1969)
325	City of Edmonton	Police Station (931-36-04-01,1968)
326-328		Relief Sewer (931-36-04-03,1984)
329-334		Relief Outflow (931-36-04-04,1984)
335-337		Strathcona Wire (1974)
338		Police Station (1968)
339		Shaft (1985)
340-342		Sewer (1969)
343	Hardy Assoc.	Project Century (E-2571,1973)
344		Bellamy Hill (B-4372,1978)
345		Workers Compensation (E-1677,1968)
346-347	EBA Consulting	Edmonton Convention Centre (1-1099,1975)
348-349		High Rise (16-2215,1978)
350-351		Police Headquarters (16-2363,1978)
352		Daon Bldg. (1-12-144,1973)
353-354		Manulife Insurance (E-425,1972)
355		Twin Office Towers (E-688)
356		Financial Bldg. (E-772,1977)
357		High Rise (16-1827)
358	EBA Consulting	Numac Oil and Gas (E-396,1971)
359		Hotel Office Complex (106-3203,1981)
360		Qualico Centre (106-2665,1979)
361		Patrician Land Bldg. (106-3404,1981)
362		High Rise (16-2138,1978)
363		Office Tower (1-1410,1975)
364		Madison Bldg. (1972)
365		Apartment (106-2769,1980)
366		Apartment (1969)
367-376	Bayrock and Berg	Geology of the City of Edmonton (1966).
377	City of Edmonton	McDougall Tunnel (931-36-23-08,1984)
378	City of Edmonton	Relief Sewer

		(931-36-06-02,1984)
379		Kitchener Park (934-36-05-01,1967)
380		Sewer Shaft (934-36-04-06,1985)
381		Sewer Line (934-36-03-16,1984)
382		Urban Renewal (934-36-07-06,1966)
383		Telephone Exchange (934-36-07-05,1969)
384	Whitmore & Assoc.	Baker Clinic (67-4,1967)
385	Curtis Engineering	High Rise (277-87-4E,1977)

EBA Consulting - Light Rapid Transit, 1975

386	TH-12	404	38
387	22	405	9
388	10	406	3
389	20	407	34
390	19	408	2
391	18	409	1
392	11	410	8
393	14	411	31
394	23	412	21
395	33	413	7
396	6	414	24
397	15	415	25
398	17	416	26
399	5	417	27
400	36	418	28
401	35	419	29
402	37	420	30
403	4		

Thurber Consultants - Light Rapid Transit, 1979, 1980

421	TH 79-24	439	11
422	1	440	22
423	25	441	12
424	2	442	20
425	26	443	13
426	3	444	14
427	4	445	23
428	5	446	15
429	18	447	16
430	19	448	17
431	27	449	80-6
432	6	450	2
433	7	451	1
434	28	452	3
435	8	453	7
436	9	454	8
437	10	455	4
438	21	456	5

457	Hoggan Eng.	LRT,(M7,1978;in Thurber,1981)
458	Curtis Eng.	LRT,(2,1979; in Thurber 1981)
459	EBA	LRT,(4,1976; in Thurber 1981)

Hardy Assoc. - Light Rapid Transit, 1985, 1986

460	H86-55	495	86-72
461	54	496	85-9
462	85-36	497	86-73
463	1	498	85-22
464	38	499	86-75
465	2	500	85-21
466	86-52	501	86-74
467	53	502	85-10
468	51	503	20
469	85-3	504	11
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477	66	512	85-12
478	85-33	513	41
479	86-68	514	86-58
480	85-5	515	85-26
481	86-64	516	86-57
482	85-32	517	85-18
483	86-63	518	86-56
484	85-6	519	85-27
485	86-69	520	17
486	85-42	521	13
487	31	522	16
488	86-61	523	86-48
489	85-7	524	85-28
490	86-60	525	12
491	86-70	526	86-82
492	85-8	527	85-37
493	86-71	528	86-81
494	85-23	529	85-14

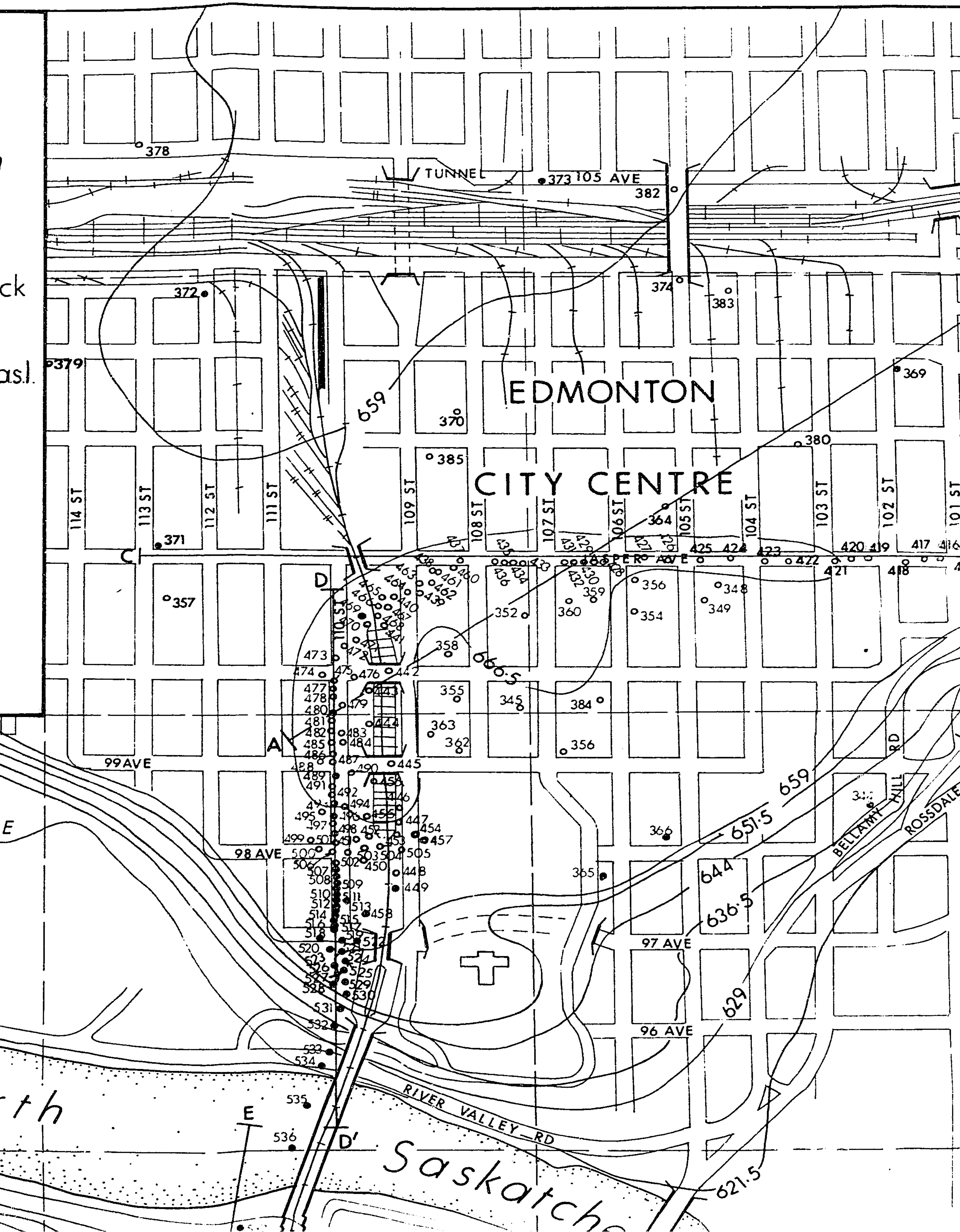
Thurber Consultants - Light Rapid Transit, 1985

530	T85-N1	537	S1
531	N6	538	S2
532	N3	539	S3
533	N5	540	S10
534	N4	541	S12
535	R6	542	S13
536	R3	543	S6

Thurber Consultants - Light Rapid Transit, 1985, 1986

544	T85-T1	548	T3
545	T2	549	T11
546	T9	550	T13
547	T14	551	T10
552	T15	582	T27
553	T4	583	T24
554	T16	584	T23
555	T5	585	T22
556	T17	586	T25
557	T6	587	T26

558	T12	588	T21
559	U4	589	T86-S32
560	U5	590	S20
561	U6	591	S29
562	U7	592	S17
563	U3	593	S26
564	U8	594	S14
565	U2	595	T40
566	U9	596	T41
567	U10	597	T43
568	U1	598	T44
569	T20	599	T45
570	T7	600	T46
571	T18	601	T36
572	T8	602	T38
573	T19	603	T39
574	T86-S28	604	T37
575	T85-T35	605	H4
576	T31	606	H5
577	T33	607	H3
578	T32	608	H6
579	T30	609	H75
580	T28	610	H8
581	T29	611	H2
		612	H1



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ROSSDALE
RIVER VALLEY RD
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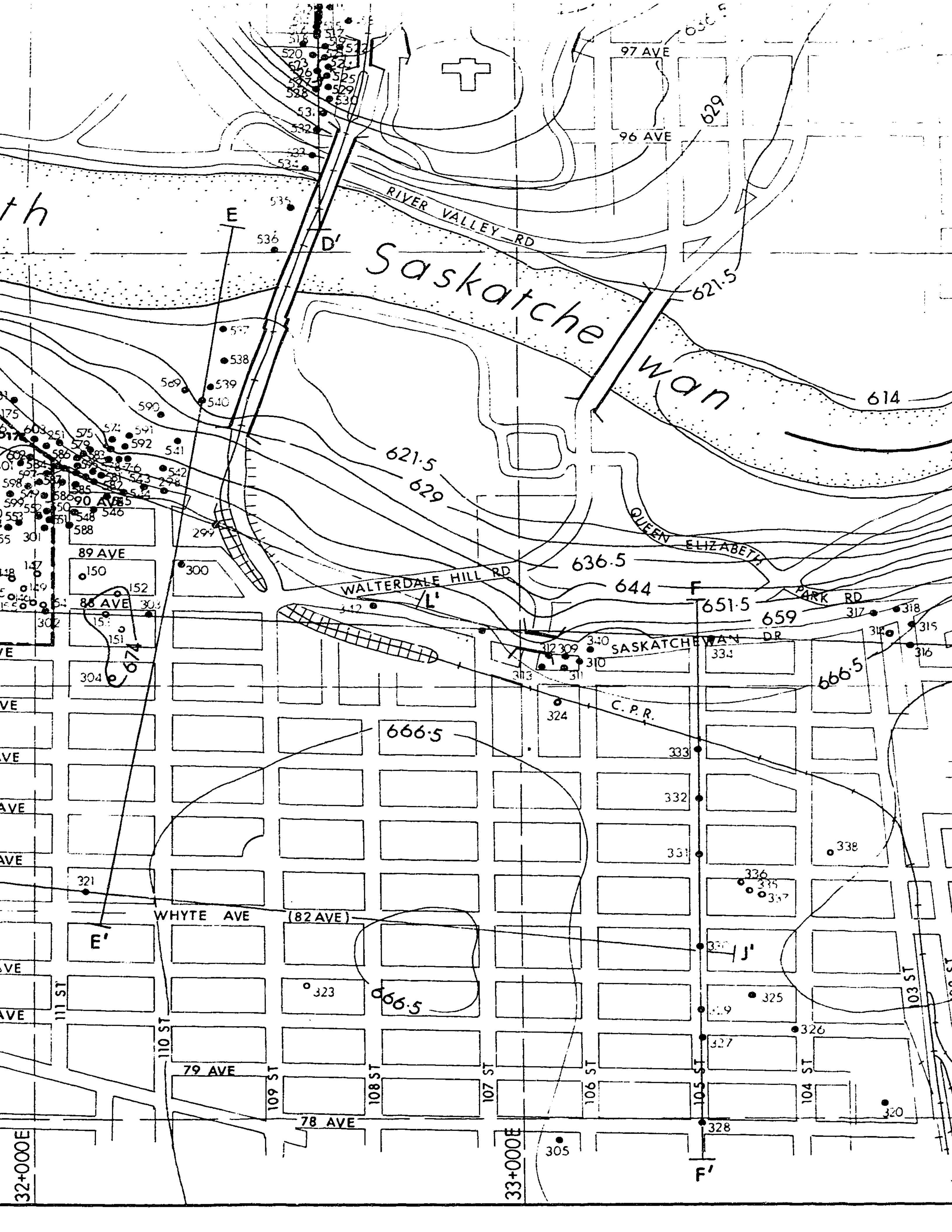

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96 AVE
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WALTERDALE HILL RD
SASKATCHEWAN DR
C.P.R.
WHYTE AVE (82 AVE)
90 AVE
89 AVE
88 AVE
79 AVE
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