A study of stratigraphy and sedimentation in the formation of a stratigraphic trap, e.g. the Bellshill lake oilfield area of Alberta, Canada

Hodgson, A. V.

Hodgson, A. V. (1967) *A study of stratigraphy and sedimentation in the formation of a stratigraphic trap, e.g. the Bellshill lake oilfield area of Alberta, Canada*, Durham theses, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/10258/

A STUDY OF STRATIGRAPHY AND SEDIMENTATION IN THE FORMATION OF A STRATIGRAPHIC TRAP, e.g. THE BELLSHILL LAKE OILFIELD AREA OF ALBERTA, CANADA.

by

A.V. HODGSON, B.Sc., C.Eng., A.M.I.M.M., F.G.S.

Thesis submitted for the degree of M.Sc. in the
University of Durham, June 1967.

CONTENTS

Page

FIGURES

TABLES

Photographs

ABSTRACT

Stratigraphic traps are, in general, directly related to their respective depositional environments. An understanding of the depositional environment is essential to successful prospecting for oil and natural gas in this type of hydrocarbon reservoir. The concept of differential compaction of a sedimentary sequence makes isopach studies of shales immediately above (and below) a lenticular sand body or a knobbed blanket sand, of considerable value in isolating areas of interest to the Petroleum Geologist. The variations in thickness of these shales are independent of present day structure and these studies of such genetic sequences serve as real indicators of sand bodies and their depositional trend. Structure contour maps drawn on a reliable time marker (e.g. a marine transgression) within the selected genetic sequence can provide the information required to select a drilling location.

In all such studies all the tools and data available to the Petroleum Geologist should be consulted and considered. This thesis is a brief account of the work of the Petroleum Geologist in the active search of oil and natural gas, the tools he uses, the data he consults, the regional depositional environment he must understand and a description of a typical example, the Bellshill Lake Oilfield, of one of the projects he is likely to be called upon to undertake.

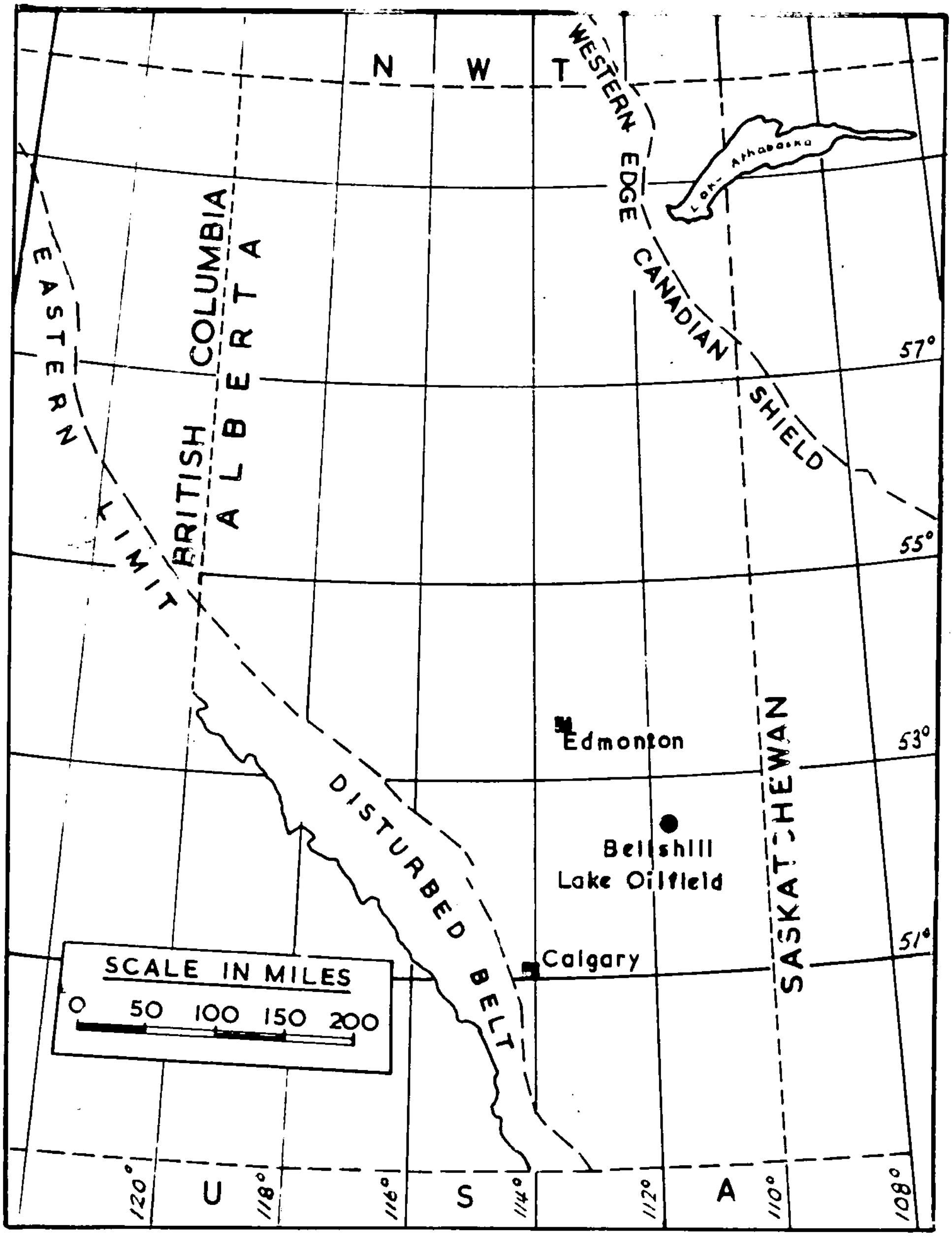
INTRODUCTION AND OBJECT

The object of this thesis is to show, in part, the studies which a Petroleum Geologist is required to make and the methods with which he is expected to be familiar in the evaluation of available data and the production of evidence for new prospecting areas. Sub-surface geological exploration techniques used include contour and isopach mapping, cross sections, Schlumberger electric and other logs, stratigraphic logs, lithofacies maps, together with studies of the sedimentary petrology and palaeontology of borehole rock chippings and cores, physical and chemical analyses of sediments, and the interpretation of porosity and permeability data and seismic maps. The palaeogeography of the information studied must be determined and the influence of palaeotopography, sedimentation (e.g. provenance) mode of transport, deposition and reworking, should be appreciated. The influence of overburden on porosity and permeability, the drape of overlying strata possibly producing other potential oil bearing horizons and the influence of secondary cementation partially or completely occluding the reservoir has to be investigated. A wide understanding of geologic principles has to be used in locating possible areas suitable for trapping oil and/or natural gas. An awareness of new techniques and current literature is naturally also very important.

The Bellshill Lake Oilfield is located (Figure 1) on the eastern flank of the Alberta Syncline (the Western Canadian Sedimentary Basin). It is a stratigraphic trap located in the Lower Cretaceous System.

The account is divided into two parts. In the first part the following topics are considered: regional setting, stratigraphic correlation and palaeogeography, petrography, economic geology of petroleum and natural gas and the formation fluids and the migration of hydrocarbons in the relevant part of the Lower Cretaceous of Western Canada. The second half presents a more detailed study of the Bellshill Lake Oilfield area with various maps, cross sections, sediment analyses and field and engineering data typically used by the Petroleum Geologist together with some other observations of a more academic nature.

FIGURE I.
LOCATION MAP



Index Map of Alberta showing area studied and location of Bellshill Lake Oilfield.

REVIEW OF PREVIOUS WORK

A great deal of material on the Lower Cretaceous of the Western Canadian Sedimentary Basin is available for study and the writer has drawn freely on the literature from many sources. This quantity of literature is due to the large number of porous horizons in the succession in which commercial quantities of hydrocarbons have accumulated and been located.

The investigation is aided by the relatively shallow depth, approximately 3000', which makes for a relatively inexpensive drilling operation if this horizon is the target zone. The Lower Cretaceous of Western Canada is a very prolific hydrocarbon-bearing succession and economically is third in importance in the volume of recoverable reserves of hydrocarbon in this area (see page 75).

A very short account of the more important published information follows. The full details of the publications are listed in the references (pages 150-163). It will also be appreciated that volumes of information lie unpublished and locked away in oil company files but the writer has drawn freely on his own work while an employee of The Sun Oil Company in Calgary, Canada, and on verbal communications with his many associates in the industry to aid in the specific and regional picture of the area described.

Hume and Hage (1941), discussed the general geology of the Wainwright-Lloydminster area (Figure 8, No. 3 area) and suggested that the area is on the western edge of a Lower Cretaceous seaway. They implied correlations with the Athabasca River Area to the North (Figure 8, No. 4 area).

Nauss (1945), studied the Cretaceous stratigraphy and microfauna of the Vermilion area (west of Lloydminster) and the genetic relationship of the subsurface Lower Cretaceous in each central Alberta to that along the Athabasca River. He introduced the name Mannville Formation and divided it into six members. Marine microfossils were obtained from the Cummings Member (equivalent to Ostracode Zone and Glauconitic Sandstone, Figure 3).

Wickenden (1948), divided the Mannville Formation at Lloydminster into three units and considered it to have been deposited as a delta in the western margin of a shallow seaway. (Figure 3)

Layer (1949), described the Mannville equivalent at Leduc, near Edmonton (Figure 1) and divided it into an upper "Coaly Series", a "Glauconitic Sand Series" and a lower "Quartz Sand Series".

Hunt (1950), erected the Ellerslie Member from Layer's "Quartz Sand Series". The type section was designated by Hunt as the Whitemud oilfield between Leduc and Edmonton.

Lockwood and Erdman (1959), drew attention to the Lower Cretaceous sands and their relationship with the sub-Cretaceous erosional surface.

Loranger (1951), described a zone of fresh to brackish and possibly marine ostracods which occurs immediately above the Ellerslie Member in the Edmonton area and indicates the southward transgression of the boreal sea through Central Alberta and southwards. Correlations throughout Alberta and the Foothills were based on this microfauna.

Badgley (1952), studied the regional aspects of the Lower Cretaceous of Central Alberta and this was the most comprehensive study up to that time. He raised the Mannville Formation to Group status to include the McMurray, Clearwater and Grand Rapids formations. He introduced the name Deville Formation and the "Glauconitic Sandstone" he called the Waliskaw Member.

Workman (1959), described the rocks of the Blairmore Group (correlative with the Mannville Group) in the sub-surface of Alberta.

Glaister (1958), published a detailed study of the petrology of the sandstones in the Blairmore Group and the following year (Glaister, 1959), described and compared the Lower Cretaceous of Southern Alberta with other areas particularly in the Sweetgrass Arch area (Figure 8, No. 1 area).

Rudolph (1959), in a note, described the development of the Bellshill Lake Oilfield to that date.

Williams (1963), published a resumé of a doctorate thesis in which he described the stratigraphy, the petrology and compared

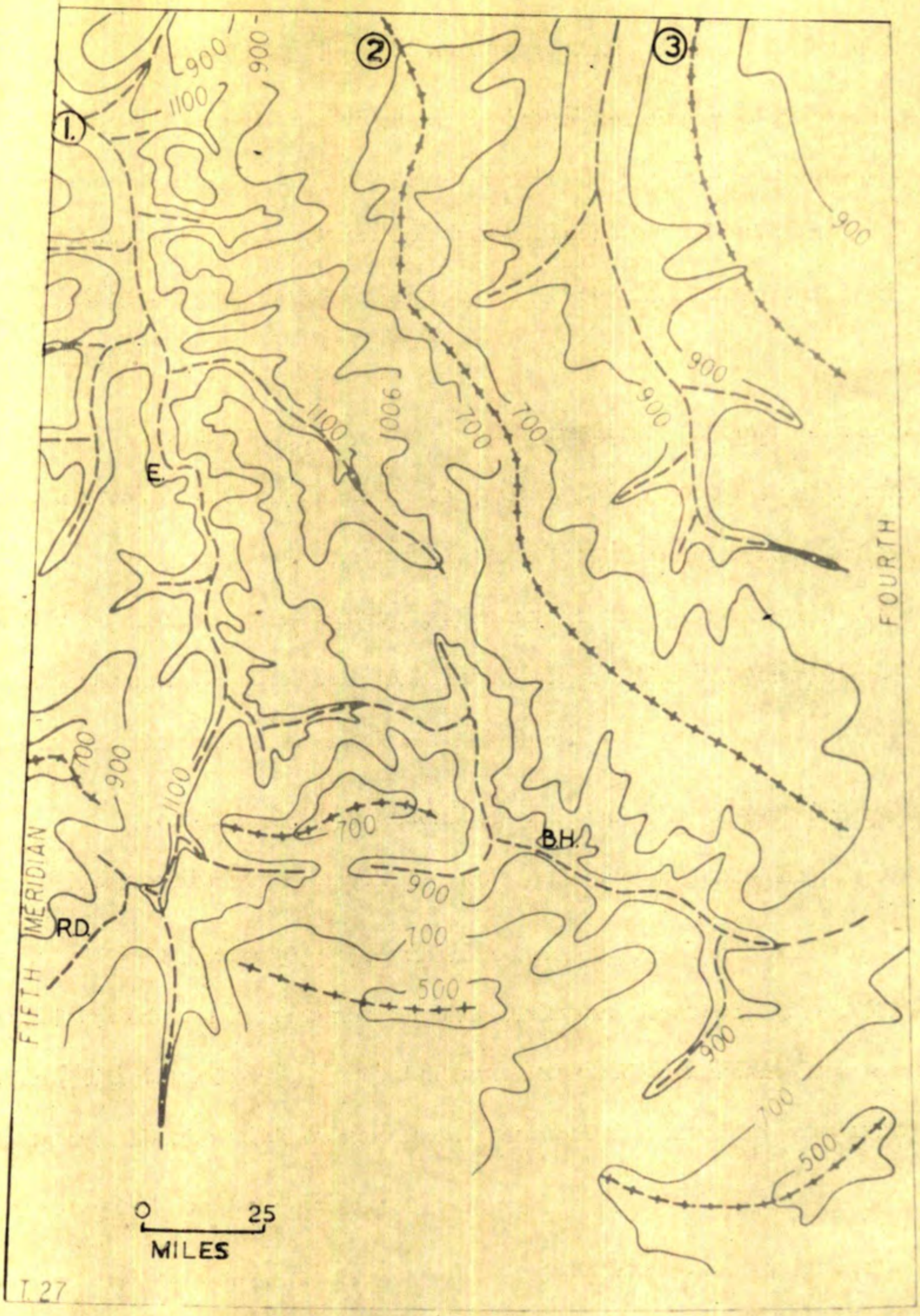


FIGURE 2.

Isopach of Lower Cretaceous strata in Central Alberta to show the Palaeozoic Erosional Surface — ① Edmonton Channel, ② Wainwright Ridge, ③ St. Paul Channel.

B.H.- Bellshill Lake, E.- Edmonton, R.D.- Red Deer.

various correlations, of the Mannville Group of the Alberta Sedimentary Basin.

Finally, Rudkin (1964), in an excellent chapter in the Geological History of Western Canada edited by McCrossan and Glaister summarised the general geology of the Lower Cretaceous in the Western Canadian Sedimentary Basin.

REGIONAL STRATIGRAPHY

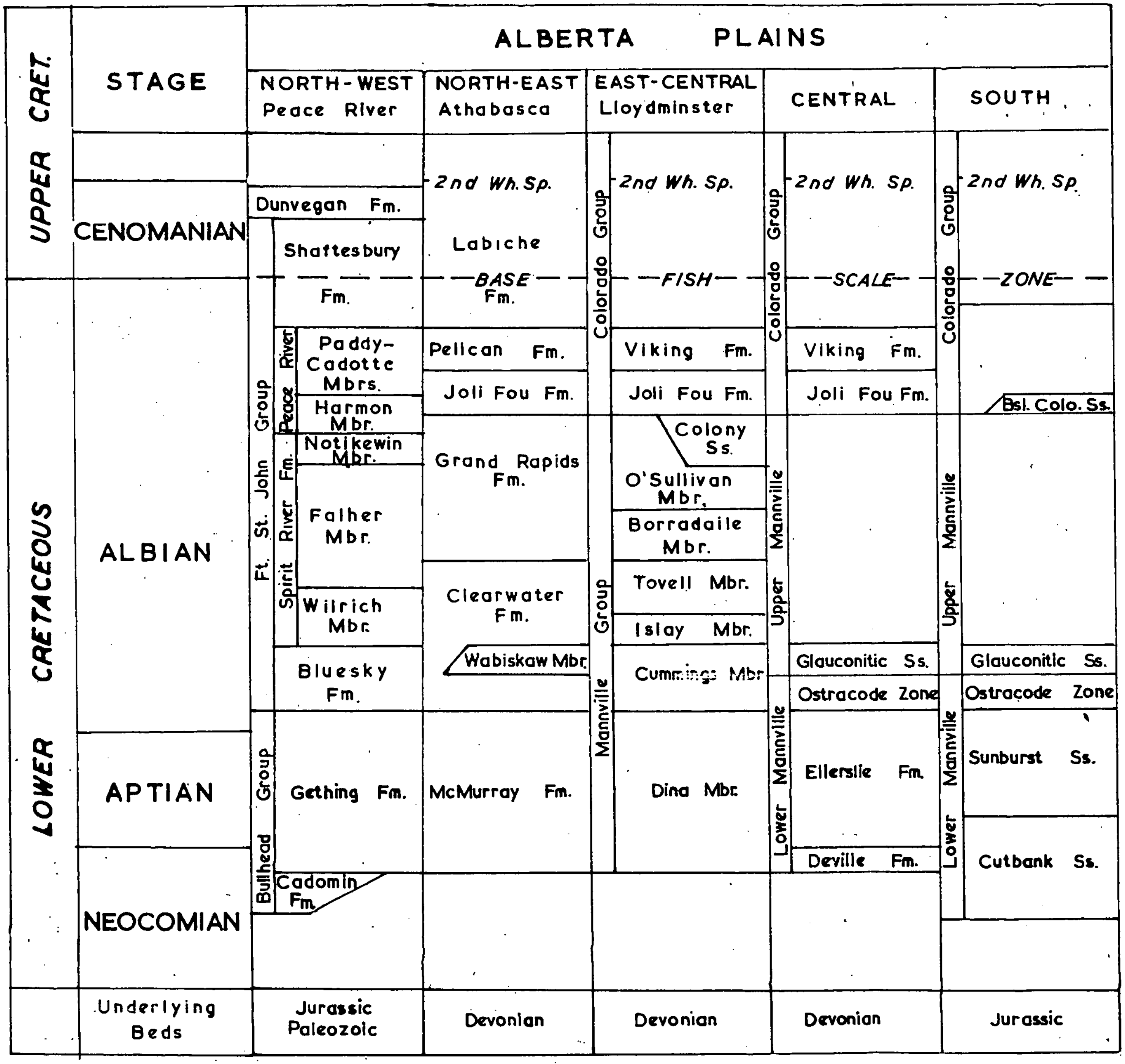
The Lower Cretaceous rocks of the Western Canadian Sedimentary Basin form an uninterrupted sequence of entirely sedimentary deposits representing all the early Cretaceous epoch with the possible exception of the early Neocomian (Figure 3). The deposits are essentially non-marine but are progressively onlapped by a transgressive boreal sea which both reworked and winnowed the non-marine sandstones and deposited marine shale, limestone and sandstone (the Ostracode Zone and Glauconite Sandstone).

The Cretaceous beds overlap, from south west to north east, with slight angularity, on an erosion surface cut across Jurassic, Mississippian, and Devonian rocks (Figure 5).

The Lower Mannville succession is essentially a basal fill deposit and represents the first sedimentation after a long period of erosion. The rocks are all non-marine except in the extreme north west of the basin where the boreal sea had already started its advance (Figure 4).

The Upper Mannville is a mixed facies due to advance and retreat of the sea. The Lower Colorado represents a complete marine inundation predominantly from the Arctic but the presence of a pelecypod *Inoceramus comancheanus* in the Joli Fou Formation indicates the advance of the Gulfian Sea from the south. The boundary of the Lower and Upper Cretaceous is taken at the Base of the Fish Scales Zone,

FIGURE 3. STRATIGRAPHIC CORRELATION CHART.



which spreads over the whole basin and is easily identified lithologically from the abundant fish scales present and also by a characteristic kick on electric logs.

The Lower Cretaceous rocks of Western Canada illustrate a transition from an early history of orogeny, emergence, erosion and non-marine sedimentation through gradual submergence and marine transgression to a final phase of marine inundation.

The Central Plains cross section (Figure 5) shows:-

1. the western trough in the foothill region where greater subsidence occurred and the supply of non-marine clastics came from the Cordilleran Range, west of the Rocky Mountains.

2. the sub Cretaceous erosional surface from the westerly Jurassic, through Mississippian and much of the Devonian.

3. the first deposit is the Cadomin Conglomerate, predominantly meta-sediment from the Nelson Uplift (Figure 4) forming a wedge thinning eastwards.

4. overlap of the Lower Mannville Sandstones of the sub Cretaceous erosion surface to their outcrop in the Athabasca River region to the north east and close to the Canadian Shield.

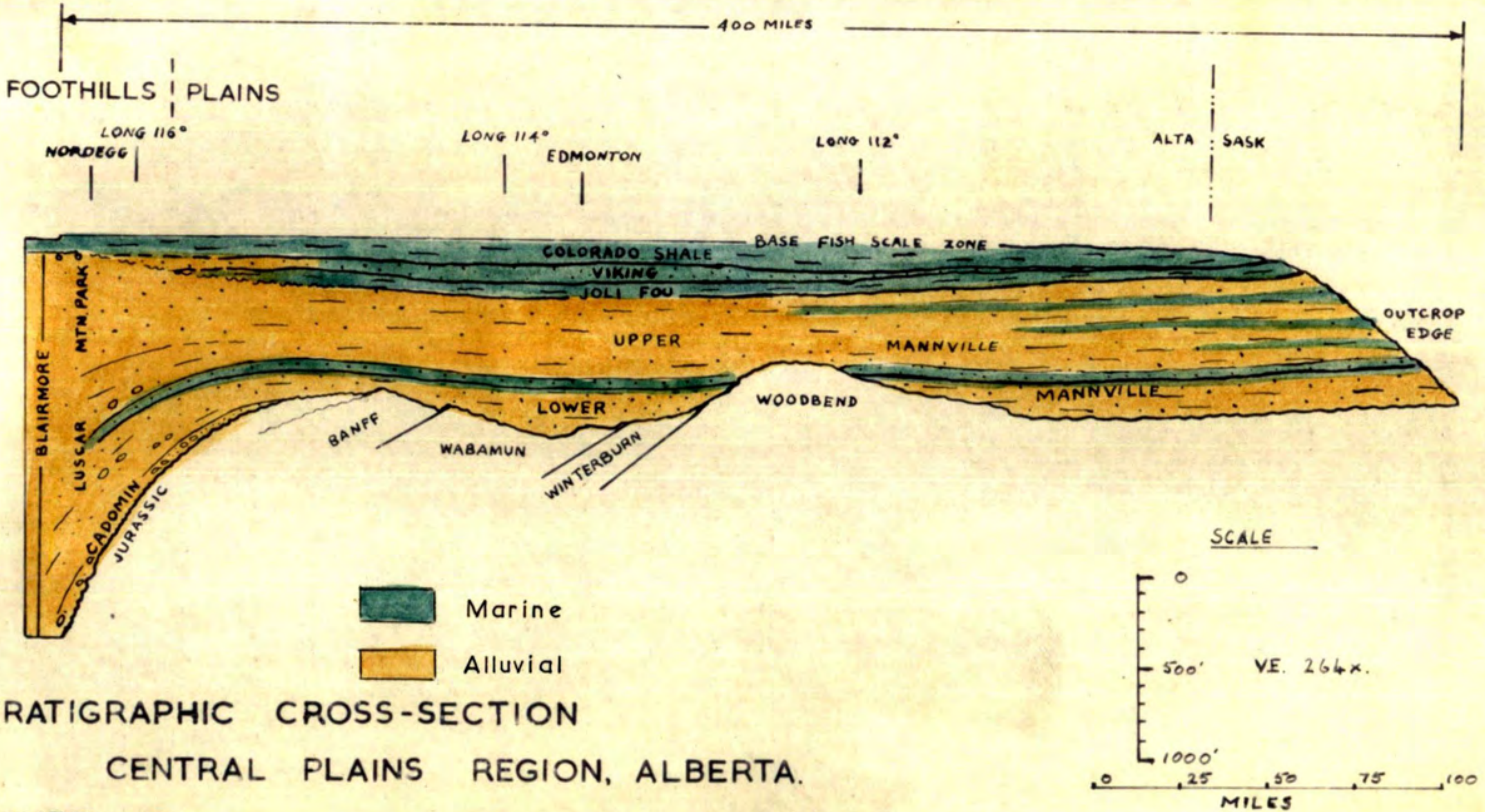
5. the resistant ridges and softer hollows on the pre-Cretaceous erosion surface (Figure 2).

PALAEOGRAPHICAL SETTING

The deposition of the early Cretaceous sediments was preceded by emergence connected with the late Jurassic, Nevadian Orogeny, and a long period of denudation. This denudation stripped away the early Mesozoic rocks and cut down into the Palaeozoic strata progressively from the west (Figure 5). The early Cretaceous sediments accummulated on a mature surface of moderate relief less than 400' in elevation and averaging 2-300', with broad valleys and rounded ridges sculptured mainly in Palaeozoic carbonate rocks (Figure 5).

The topography had a profound effect on the distribution and lithology of the Lower Cretaceous sediments. These are the quartzose sandstones of the Ellerslie Formation and its correlatives which accummulated only in topographically low areas or on the flanks of highs. The distribution of these sediments may be interpreted as the result of typical alluvial infilling or flood plain accummulation.

The most striking features of the Lower Mannville map unit are the islands of non deposition. These represent the Aptian Archipelego stretching south east to north west from south west Manitoba across the Plains to north east British Columbia (Figure 4). These islands were ridges of relatively resistent Devonian and Mississippian beds e.g. the Wainright Ridge is formed of resistent clastics and carbonates of the Winterburn Group (D_2). The Edmonton



STRATIGRAPHIC CROSS-SECTION
CENTRAL PLAINS REGION, ALBERTA.

FIGURE 5.

Channel is eroded in the carbonates and limy shales of the Wabamun Group (D_1) in the Upper Devonian. (Figure 5)

Continued subsidence of the geosyncline allowed the transgression of the arctic (boreal) sea into Central Alberta reworking at the top the alluvial and lacustrine current bedded sands of the Ellerslie Formation. The deposition of the Ostracode Zone, also called the Calcareous Member, and the Glauconitic Sandstone, also called the Wabiskaw Member, above the Ellerslie Formation indicates this change from alluvial through to marine and back to alluvial sedimentation and corresponds to transgression and regression of the shoreline.

Longshore currents in front of this shifting strand line would have reworked the top of the Ellerslie Sandstone. Both the alluvial plains and the sea floor may be vizualised as essentially flat. Even a slight change in relative sea level of the Lower Cretaceous exogeosyncline (Kay 1951) brought about a considerable lateral displacement of the shoreline without producing a conspicious unconformity.

The Bellshill Lake field lies in part of the Edmonton Channel south east of Edmonton and on the flanks of the Wainwright Ridge over which the Ellerslie Formation is largely absent as it is over any of the topographic highs in the area. This part of the erosional trough, which trends north west is 15 to 20 miles wide and nearly 300' deep.

The Canadian Shield to the east and north east and these Palaeozoic topographic features were undoubtedly the source of the Lower Mannville Group sands. The configuration of the Palaeozoic surface also very probably affected the currents which caused the winnowing of lenses within the Elleslie Sandstone before the deposition of the Ostracode Zone and Glauconitic Sandstone. Depositional conditions appear similar throughout and detailed correlations can be made between wells many miles apart but in similar positions in the trough (c.f. electric log cross section across Bellshill Lake Oilfield area, Figure 21).

STRATIGRAPHY OF THE LOWER MANNVILLE GROUP OF EAST CENTRAL ALBERTA (FIGURE 3).

The Mannville Formation named by Nauss in 1945 from the Vermillion area of East Central Alberta (Figure 3, Column 3) includes all beds between the Palaeozoic unconformity and the base of the Colorado Group. Arenaceous foraminifera found near the middle of the formation in a marine tongue indicates Lower Cretaceous age for this horizon. This is the Calcareous Member or the Ostracode Zone overlain by the marine Glauconitic Sandstone and its correlative, the Wabiskaw Member.

Badgley (1952), raised the Mannville Formation to Group status and divided it into the McMurray Formation (which includes the Ellerslie Sandstone) the Clearwater Formation and the Grand Rapids Formation and he introduced the name Deville Formation or "Detrital" Zone for the detrital material on the Palaeozoic unconformity at the base of the Ellerslie Formation (Figure 3, Column 2).

Glaister (1959), separated the Formation into Lower and Upper Mannville at the top of the Calcareous Member.

Mellon and Wall (1961), refined the correlation by further palaeontological and lithological comparisons.

Williams (1963), incorporated the Deville Member with the Ellerslie Member and the Calcareous Member within the McMurray Formation.

Rudkin (1964), uses the Lower Mannville subgroup name to include the Deville Formation, the Ellerslie Formation and the Ostracod Zone instead of the McMurray Formation with its constituent members and this is the terminology followed in this account (Figure 3, Column 4).

Extensive drilling in Central Alberta, principally to Palaeozoic horizons, makes this one of the best known geological sections of Western Canada.

The Ellerslie Formation averages 200' in thickness in Central Alberta and is a pale grey to white quartzose sandstone, commonly fine grained and well sorted with silty-shale intercalations and coal traces. At the base is a residual zone of varying thickness and age called the Deville Formation overlying the eroded Palaeozoic surface. The thickness of the Ellerslie Formation is dependent on the Palaeozoic topography. The Lower Mannville is thickest and best developed on each side of the Wainwright Ridge, i.e. in the Edmonton and St. Paul Channels and is largely absent over the ridge due to non-deposition or shaling out.

The Deville Formation is restricted to hollows and the lower slopes of the sub-Cretaceous ridges. It consists of unsorted fragments of Palaeozoic rocks; olive green, brown and red waxy shales which appear to represent ancient soils of unknown age together with white corroded chert fragments and thin "salt and pepper" sandstones. The sandstones grade upwards into the Ellerslie Sandstone proper.

The Ellerslie Formation or Sandstone (the Basal Quartz Sandstone of the oil companies) is the principal facies of the Lower Mannville subgroup. It consists of quartzose sandstone, siltstone and silty micaceous and often carbonaceous shale. It is well sorted, well rounded, clean, fine to medium grained with scattered coaly or carbonaceous streaks.

The formation is gradationally overlain by 10 to 15' of dark grey to black calcareous fossiliferous shale, silty shale and calcareous sandstone called the Calcareous Member or Ostracod Zone. Gastropods and pelecypol fragments in a siderite matrix form coquinas up to 3' thick and thin "microcoquinas" of ostracod fragments are also common. The distinguishing ostracod is Metacypris persulcata which indicates a fresh to brackish shallow water environment which grades upwards into marine sediments. Loranger (1951), described the Ostracod Zone as a faunal unit but it is also a lithological unit which can be correlated with the Calcareous Member of the Southern Foothills and picked up over a very wide area of the subsurface of the Central Plains as a marker horizon on electric logs.

The Lower Mannville then, except for a few feet at the top, was deposited under continental conditions, most likely a shallow water lacustrine or fluviatile environment or at least a deltaic fresh water arm of the Lower Cretaceous sea. The Uppermost sediments grade rapidly into the overlying marine shales and sandstones of the Clearwater Formation (part of the Upper Mannville) the contact being at the base of the persistent Glauconitic Sandstone called the Wabiskaw Member (Badgley 1952, Williams 1953).

SUMMARY OF STRATIGRAPHY

After uplift of the meta-sedimentary source of sediment, and deposition of the Cadomin Conglomerate in the Foothills area at the base of the Lower Cretaceous (Figure 5), a further increase in the rate of deposition relative to subsidence initiated overlap of clastic sediments over the stable shelf to the east. In Central Alberta the westerly derived material intermixed with clastics derived from a mildly positive area to the north-east (the shield in northern Saskatchewan and Manitoba). Deposition occurred in shallow water over an erosional surface of low relief, the topographic features of which were controlled by the nature of the sub-cropping Palaeozoic formations. Valleys on the Palaeozoic surface were probably occupied by rivers flowing north-westwards over wide flood-plains in Lower Mannville time. Lakes and swamps probably occupied considerable portions of the flood-plains and were the sites of deposition of much of the Ellerslie Formation.

The Calcareous Member at the top of the Lower Mannville marks a period of stability during which fresh water limestones accumulated in numerous penecontemporaneous lakes.

The land slowly subsided and the Clearwater boreal transgressed southwards across the low lying land with its shallow lakes, the rivers were transformed into estuaries and eventually arms of the sea.

PETROGRAPHY

The Lower Mannville Group

The Lower Mannville varies in thickness from 50' - 370' due to irregularities on the unconformity. Sixty five thin sections were examined under the petrological microscope; two from the Calcareous Member, 58 of the Ellerslie Formation, and five from the Deville Member, together with hand specimens from cores.

The sequence consists of non-marine buff-white fine grained orthoquartzite (95% quartz and chert), and protoquartzite (75-95% quartz and chert), (Pettijohn 1954, McBride 1962), (see also Figure 6), calcareous in part. The sandstones are interbedded with dark grey silty shale, commonly carbonaceous, and grey siltstone. Near the top occur thin beds of tan-grey cryptocrystalline argillaceous limestone and grey calcareous shale (often with pelecypods and ostracods).

The Lower Mannville is divided into the Deville, the Ellerslie, and the Calcareous Formations.

The Deville Formation

The Deville Formation, (Badgley 1951, 1952) ≡ Detrital Zone. Type section Imperial Deville No. 1, Lsd. 9-6-51-20 W4M, (for explanation of Canadian geographical coordinates see Table 3 page 99), 3555½' - 3605'.

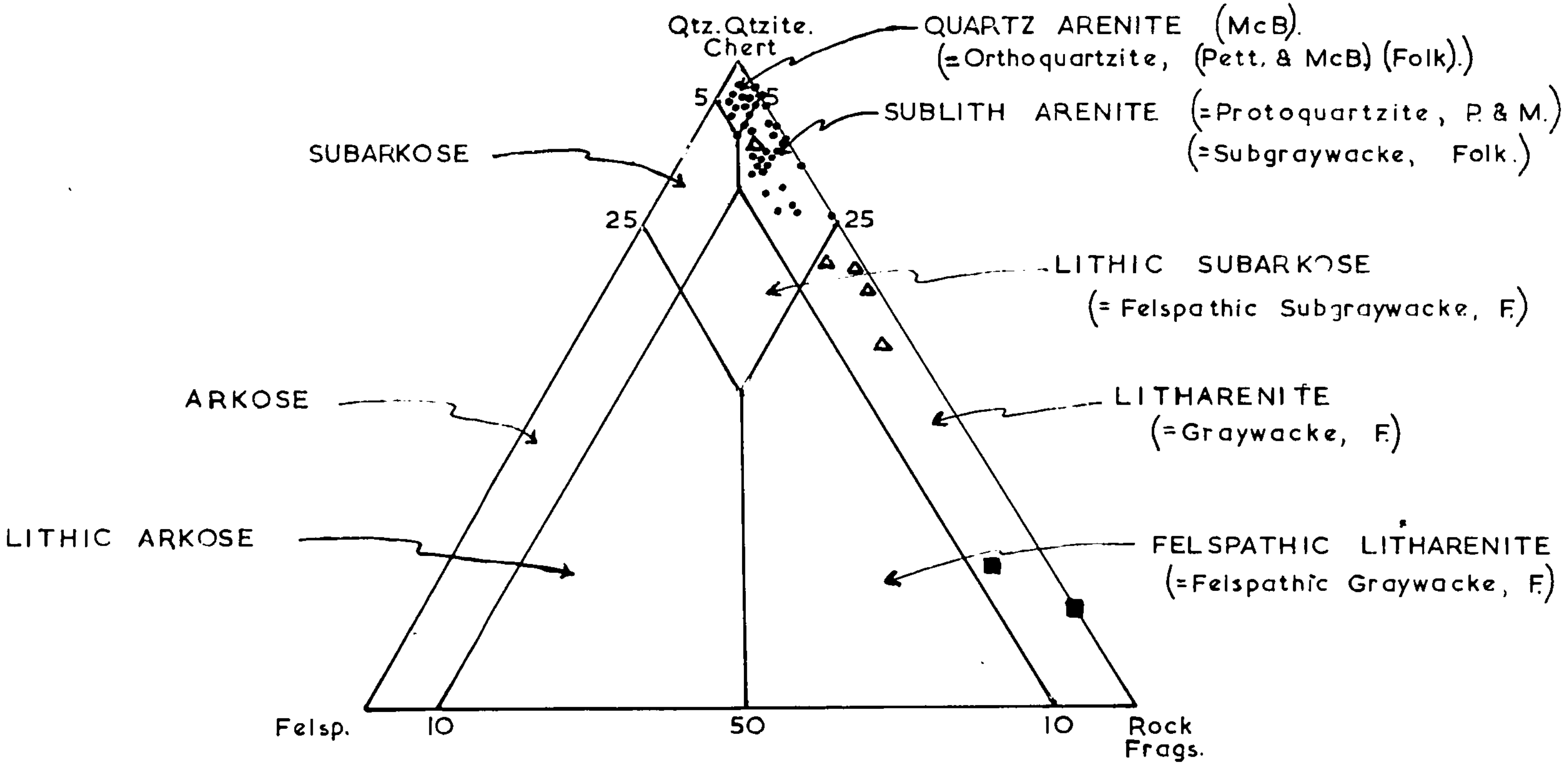
This information is characterised by extreme variability e.g. in grain size, very fine grained upto 8mm. pebbles. The constituents are angular or rounded with poor to good sorting. Porosity is less than 12%. The main constituents are quartz 30-50% and rock fragments (usually chert) 5-35%. Felspars contribute less than 3%. Also common are red and green waxy shales, greenish-grey argillaceous siltstones, pyritiferous "salt and pepper" protoquartzites with numerous green shale partings. Also brown-buff waxy silty shales occur together with pellets composed of silt sized quartz particles with siderite cement commonly embedded in shale; and nodular pebbles, often weathered white, of grey chert.

The waxy shales appear to represent ancient soils of unknown age, 0-70' thick. The sporadic distribution of this soil is to be expected from the detrital nature of the deposit which represents the insoluble residue accumulated after solution of the Palaeozoic carbonate rocks. White weathered chert is common where the plane of erosion incorporates the Rundle Limestone of the Mississippian. Since the Deville Member is usually thin or missing over the higher areas, some of the regolithic deposits were probably transported short distances from the topographic highs and deposited in the nearby lows.

The Ellerslie Formation

This is texturally a mature sandstone. It is very fine

Composition of Lower Mannville Sandstones, Lower Cretaceous, Alberta. (Classification after McBride 1963).



■ CALCAREOUS MEMBER (2 thin sections).
• ELLERSLIE FORMATION (58 thin sections).
△ DEVILLE FORMATION (5 thin sections).

FIGURE 6.

to coarse grained, generally well sorted with round to subrounded grains (photos 7, 22), porosity rises to 30% (Photo core H, and Photo 12). The deposit is coarsest at the base, often conglomeratic in part (q.v. lithologic log Figure 22) and this zone generally has the greatest porosity (q.v. shape of self-potential curve on electric log Figure 10). It grades up to massive, fine to medium grained porous sandstone and up into fine to very find grained finely laminated sandstone (core Photos).

Silty and clay sized particles in the matrix are generally less than 10% but where it does occur it can severely reduce the porosity (Photos. 9, 10). Quartz, quartzite and chert constitute 75-90% total rock and with rock fragments 1-20%, are the main components. Felspar, predominantly orthoclase, contributes 0-6%. (The thin sections are stained with sodium cobaltinitrite for identification of the potash felspar, Photos. 5 and 6). Authigenic quartz is present and forms overgrowths in optical continuity with the detrital grains (Photos. 13, 14). The new crystal face imparts a pseudo-angularity to the rounded grains. Calcite cement is occassionally present, upto 5% by volume, and barite has been recorded (Williams 1963).

Single quartz grains showing slight to strongly undulose extinction and composite grains with strongly undulose extinction are the dominant types. Globules of gas and/or liquid and fine micaceous and opaque dust constitutes most of the inclusions in the quartz grain inclusions. In grains with straight extinction the inclusions are usually randomly dispersed, whereas in grains with undulose extinction inclusions are usually aligned parallel to small fractures (Photos. 17, 18). Mica, apatite, and tourmaline are present as identifiable inclusions in the quartz grains (Photos. 13, 14).

Most adjacent grains lie with tangential (or point to point) contact (Photo 12). Straight line contacts due to pressure solution between grains is next in abundance (Photo 13) and some suturing along the contacts has occurred (Photo 15). Pressure solution has in some specimens almost completely occluded the pores (Photo 16).

Quartz grains in the porous sandstones commonly show etching, frosting and pitting along pore boundaries (Photos. 11, 12). These solution effects apparently occurred after precipitation of the authigenic silica overgrowths. Dapples (1959) ".. considered solution pitting of quartz grains to occur in the initial or depositional stage before precipitation of overgrowths." However he also stated that intrastratal solution could occur later provided the sandstone had not been deeply buried).

Core samples of the Ellerslie Sandstone show sedimentary features which indicate that it has never undergone deep burial. The most noticeable feature is the friability of the sandstone, (Photos core H, 12), even with 5-10% authigenic siliceous cement. Also the presence of authigenic quartz overgrowths; the preponderence of tangential inter-grain contacts; and the general lack of cement.

The Ellerslie Sandstones are texturally and compositionally mature and have undoubtedly passed through several depositional cycles since originating from a pre-Cambrian source.

The carbonaceous remains and sedimentary structures of the Ellerslie Sandstone in Central Alberta indicate that it was deposited in a submerging fluvial environment (Figure 22, Photo 30). Chert is a common constituent of westerly derived sediments. Because of dilution by easterly derived material the Ellerslie Formation contains much less chert than the Sunburst Sandstone, its equivalent in the south (Glaister 1959). Heavy mineral studies (Badgley 1959, Mellon 1956) indicate that the Canadian Shield was the important contributor of sediments to Central Alberta at this time. The heavy minerals, may however, also have been derived from sediments flanking the Shield and derived from it during an earlier cycle, and they are consequently 2nd, 3rd or more cycle minerals.

The Calcareous Member

The Ellerslie Sandstone in Central Alberta is gradationally overlain by dark grey to black, calcareous, fossiliferous shale, silty shale, and calcareous sandstone of the Calcareous Member or Ostracod Zone (Photos. 23 to 29, core photos 9, 10). Gastropod and pelecypod fragments in a siderite matrix form coquinas upto 3' thick and "microcoquinas" of ostracod carapaces are quite common. Sometimes "salt and pepper" sandstone lenses occur and may be porous and permeable and contain hydrocarbon, e.g. the Alexandre gasfield in Township 56, Range 27 W4M.

The fauna of ostracods, charaphytes, pelecypods, and gastropods is typical of fresh water-brackish water environments. Badgley (1952), indicated a Lower Albian age (Figures 3, 17) for the *Metacypris angularis* Zone which may be correlated with the Calcareous Member near Edmonton. It appears to be a true time horizon although limestone deposition probably persisted in some areas longer than in others. Loranger (1951) expressed the view that limestones in the Calcareous Member were probably deposited in a number of penecontemporaneous lakes rather than a single lake covering the whole area.

Conditions of Accumulation of the Lower Mannville Sediments

This lithologic sequence in the Lower Mannville is in keeping with Pettijohn's observations (1957 page 186) that the quartzite or orthoquartzite "clan/series" is characterised by increasing carbonate and terminated by a limestone.

North and East-Central Alberta had a well developed drainage system on the sub-Cretaceous surface (Figure 2). High sand to shale ratios are found on the flanks of the non-depositional ridges (Figure 4). Near Edmonton more than 300' of Lower Mannville sandstone and shale accumulated in a major river valley between two topographic ridges. The Lower Mannville thickness westwards because of greater subsidence and closeness to one of the sources of sediment (Figure 5). High sandstone content east of the Wainwright Ridge indicates a shield source for the McMurray and Dina Formations. (Figure 3, column 3)

In North-West Alberta, British Columbia, and the North-West Territories the Lower Mannville beds are marine shales representing the first stages of the southwardly transgressing Cretaceous boreal sea.

Towards the end of the Lower Mannville time this sea probably made several brief incursions over the plains area about as far south as latitude 53° North and reworked the non-marine sands, winnowing, sorting and generally improving the reservoir character. The plains between latitudes 53° and 57° North are considered to be a mixed marine and non-marine environment. South of 53° North the environment is entirely non-marine throughout Lower Mannville times.

DESCRIPTION OF THIN SECTION PHOTOGRAPHS

Microscope: Leitz Ortholux.
Camera : Leitz Orthomat.
Film : Ilford Pan F, A.S.A. 50.
Scale : Long edge of photographs = 3.5mm @ x72.5 and
= 0.75mm @ x450.

Photo. 1. Ellerslie Formation.

Whitemud 15-14-51-25 W4M, @ 4070'.

x65, Plain polarised light.

Orthoquartzite, fine to medium grained, subangular to subrounded, long grain and concavo-convex grain contacts dominant, some sutured margins with occlusion of some pore spaces reducing porosity; other intergranular interstices filled with clay mineral matrix.

Photo. 2. Ellerslie Formation.

Morningside 14-20-41-27 W4M, @ 3565'.

x65, Plain polarised light.

Orthoquartzite, fine grained, subangular, long grain contacts dominant over tangential grain contacts, sutured margins; some yellow stained potash felspar grains showing cleavage; some micaceous flakes; clay mineral matrix.

Photo. 1.

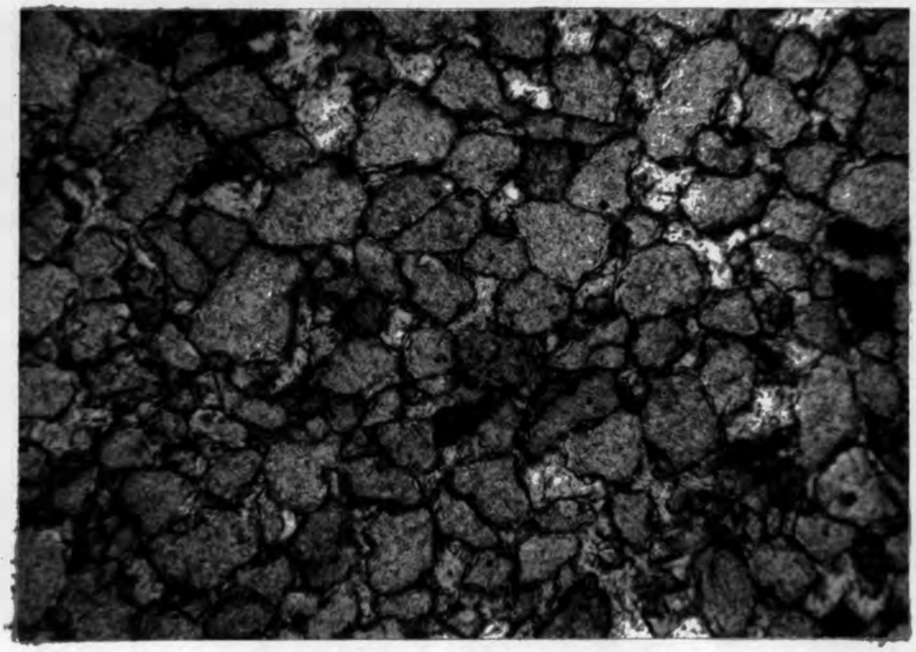
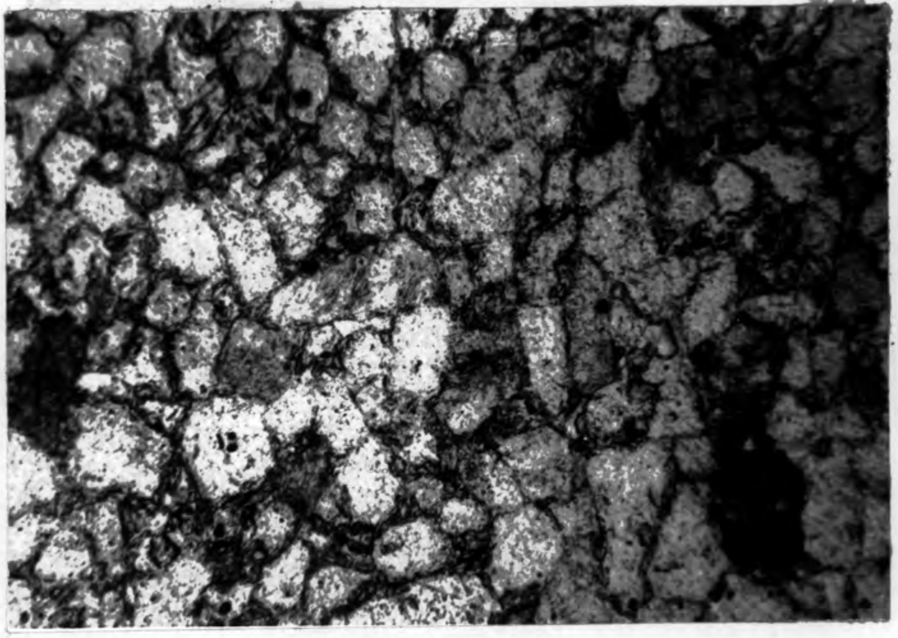


Photo. 2.



Ellerslie Formation, x65, P.P.L. Fine grained orthoquartzite, yellow stained potash felspar (F.), clay mineral matrix.

Photo. 3. Top of Ellerslie Formation.

Pinedale 16-24-54-17 W4M, @ 2710'.

x72.5, Ordinary light.

Orthoquartzite, fine grained, subrounded, corroded margins. Pyritic cement, (pyrite was found in other thin sections, generally as small anhedral grains or crystals. Where it does occur as a cement it is patchy in distribution and only binds a small number of sand grains together). A woody plant fragment, in oblique longitudinal section, shows a node. This large woody fragment measured 3mm. long x 2mm. wide.

Photo. 4. Ellerslie Formation.

Sprucefield 1-31-60-19 W4M, @ 2440'.

x65, Ordinary light.

Carbonaceous plant remains about 4mm. long, in an indurated sandstone, with a clay matrix. Low porosity and permeability.

Photo. 5. Ellerslie Formation.

Sprucefield 1-31-60-19 W4M, @ 2440'.

x65, Plain polarised light.

Protoquartzite, fine to medium grained, subangular to subrounded, quartz and quartzite grains, rock fragments, frosted, pitted and with some inclusions; and a felspar fragment showing good cleavages. Fragments bound together by a clay mineral matrix. Low porosity and poor permeability.

Photo. 6. Ellerslie Formation.

Sprucefield 1-31-60-19 W4M, @ 2440'.

x65, Crossed polars.

Showing multiple twinning on plagioclase felspar fragment and varying extinction on rock and quartz grains.

Photo. 7. Ellerslie Formation.

Whitemud 15-14-51-25 W4M, @ 4070'.

x65, Plain polarised light.

Orthoquartzite, fine to medium grained, subangular to subrounded, surface relief etched and pitted, long grain and concavo-convex grain boundaries and sutured margins common, indicative of compression and moderate pressure solution effects. Angularity of some grains may be due to recrystallisation of silica around the quartz grains.

(cf. Photo. 13, 14).

Photo. 8.

Same as Photo.7.But with crossed polars.

Quartz grains in different extinction positions.

Photo. 3.

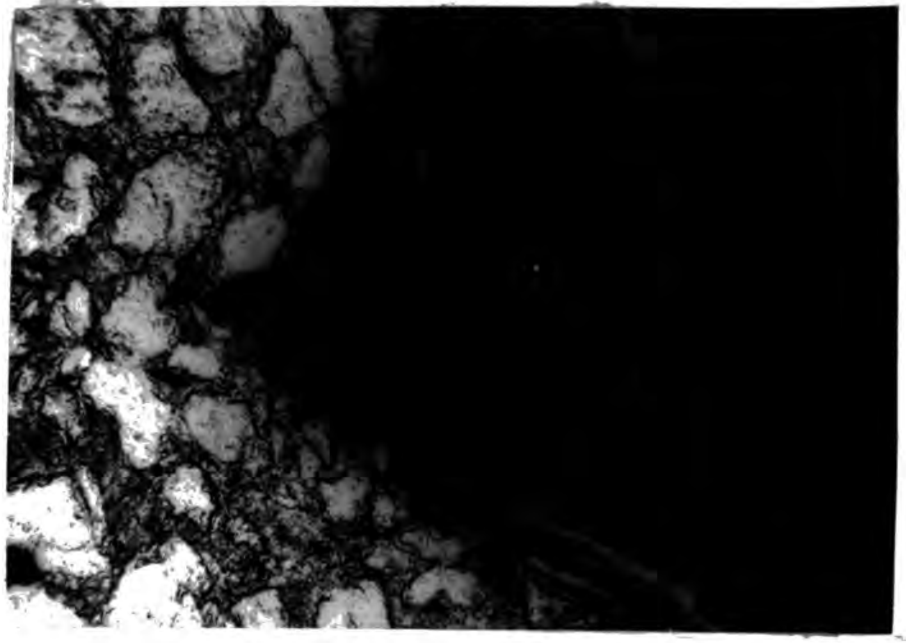
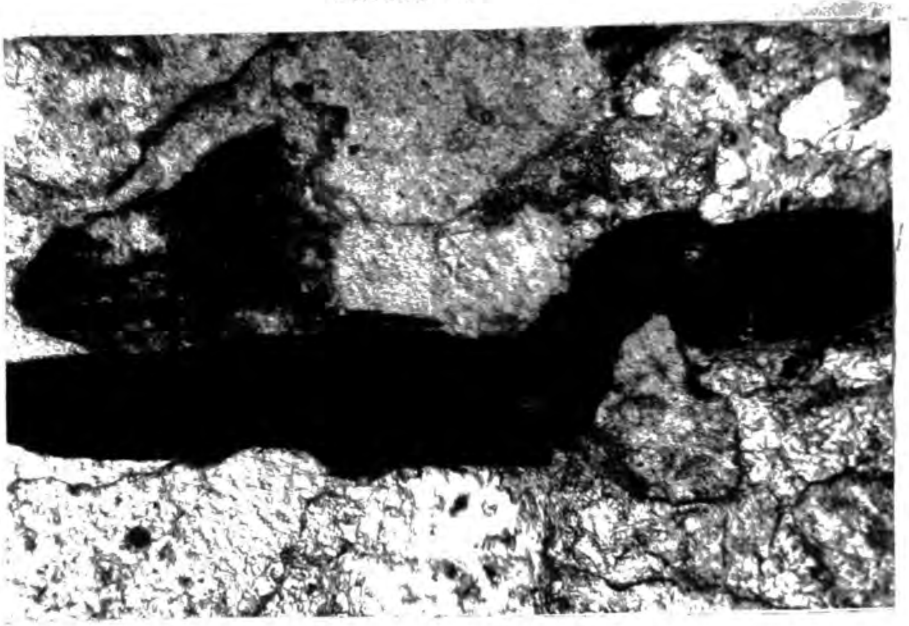


Photo. 4.



Ellerslie Formation, x72.5, O.L. Carbonaceous plant remains.

Upper: Large woody node in pyrite cemented orthoquartzite.

Lower: Plant fragment c. 4mm. long.

Photo. 5.

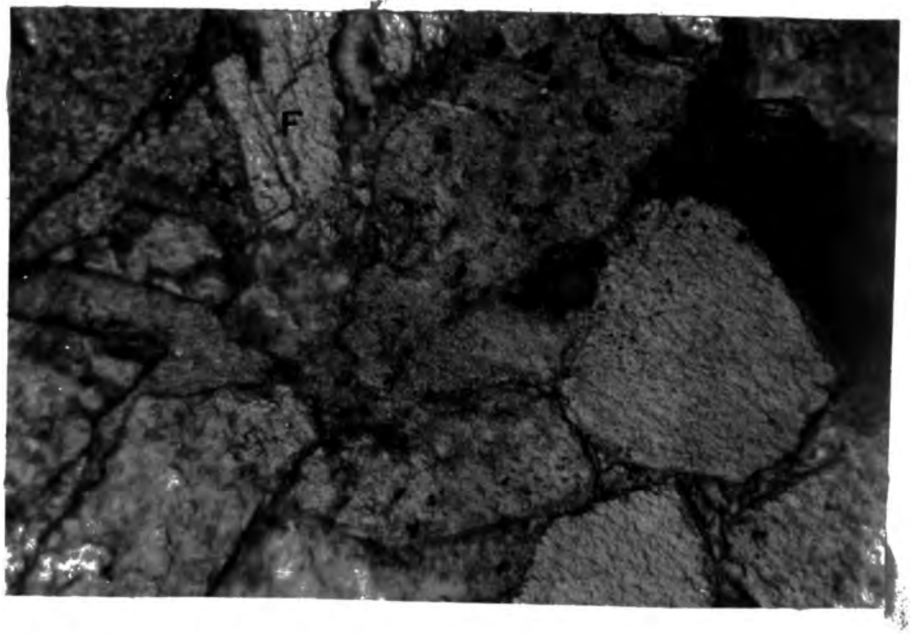
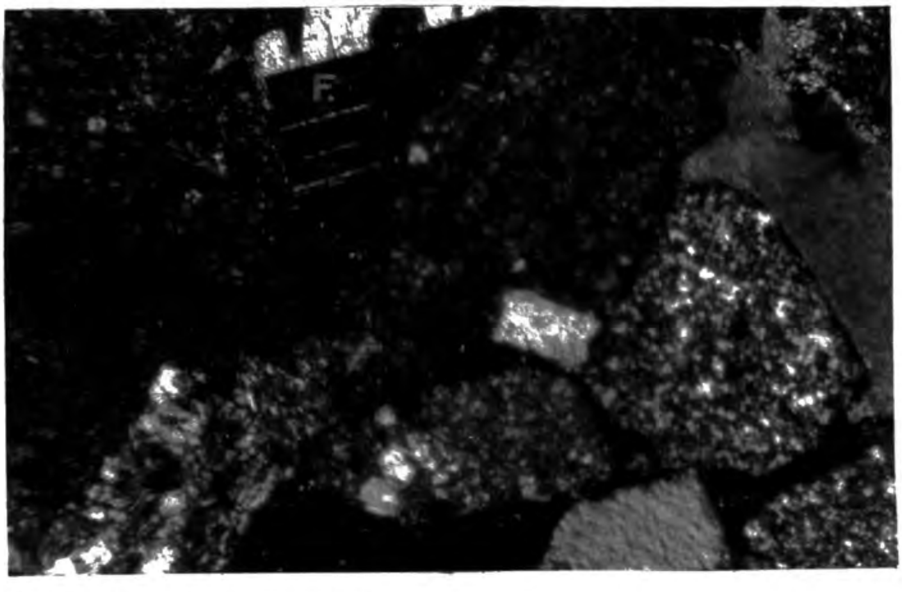


Photo. 6.



Ellerslie Formation, x65.

Upper: P.P.L. Medium grained protoquartzite, felspar fragment (F.) showing good cleavages.

Lower: X.P. Multiple twinning of felspar, varying extinction on rock fragments.

Photo. 7.

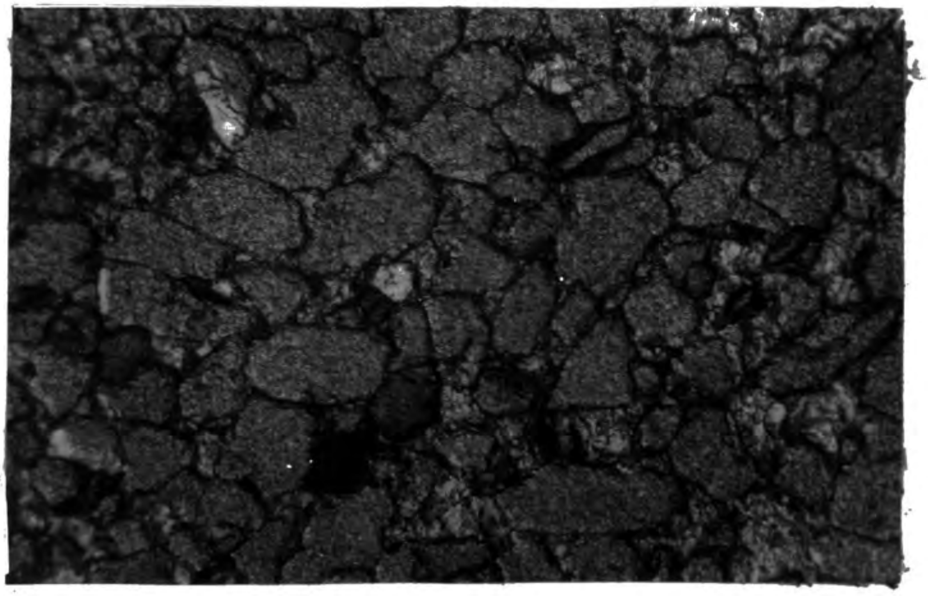
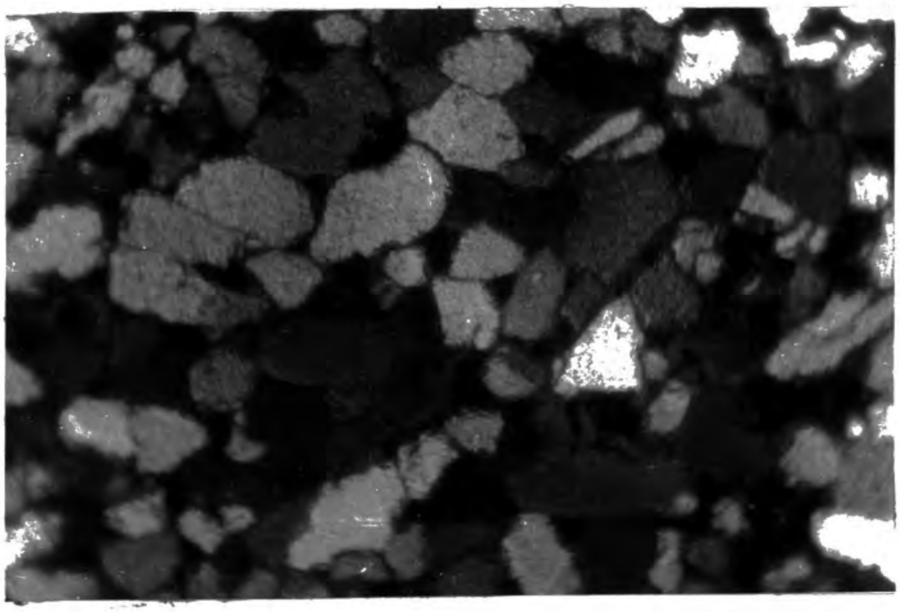


Photo. 8.



Ellerslie Formation, x65.

Upper: P.P.L. Fine grained orthoquartzite from type well.

Lower: X.P. Different extinction positions of quartz grains.

Photo. 9. Base of Calcareous Member.

Jarvie 7-22-63-1 W4M, @ 2845'.

x72.5, Ordinary light.

Protoquartzite, (cf. Figure 6), poorly sorted, fine to medium grained, angular to subrounded, quartz, rock fragments, and carbonaceous remains in a clay mineral matrix. Low porosity and poor permeability.

Photo. 10. Base of Wabiskaw Member.

Sprucefield 1-31-60-19 W4M, @ 2350'.

x72.5, Ordinary light.

Protoquartzite, silty, through fine grained to medium grained, poorly sorted, subangular to subrounded. Clay mineral matrix, low porosity, poor permeability. Note inclusions in large grain. This specimen is a sample of the accumulation deposited during the marine transgression.

Photo. 11. Ellerslie Formation.

Whitemud 15-14-51-25 W4M, @ 4070'.

x450, Ordinary light.

Etched surface of a "floating" quartz grain, also showing good roundness.

Photo. 9.

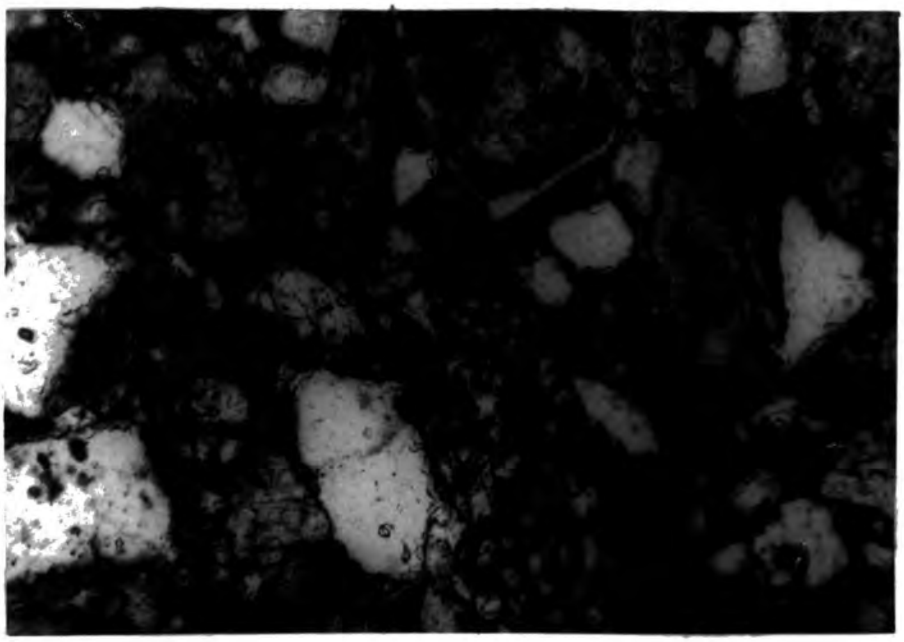
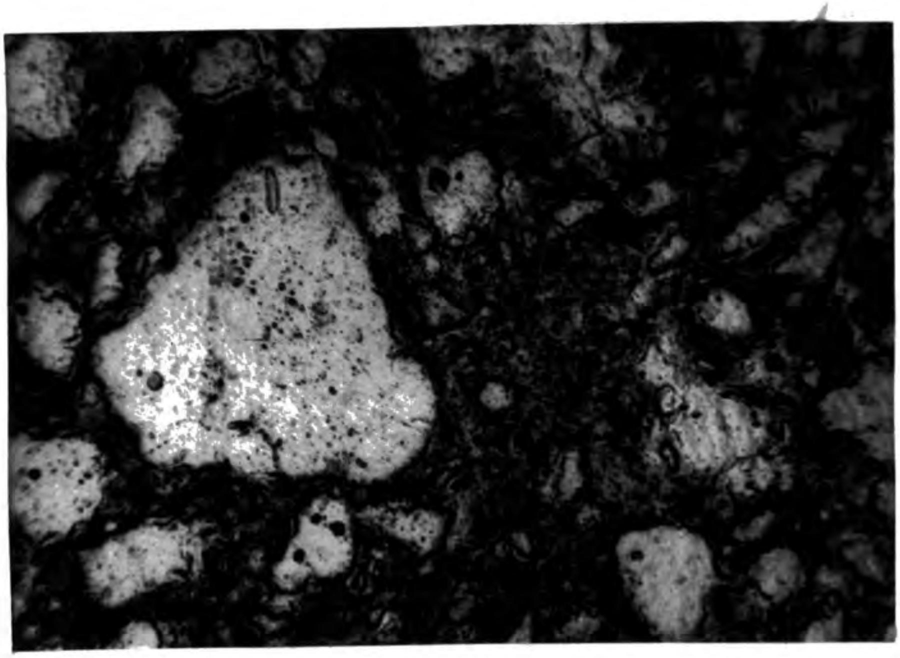


Photo. 10.



Poorly sorted fine-medium grained protoquartzite, low porosity, poor permeability. x72.5, O.L.

Upper: Calcareous Member. Lower: Wabiskaw Member.

Photo. 12. Ellerslie Formation.

Whitemud 15-14-51-25 W4M, @ 4070'.

x450, Ordinary light.

Etched quartz grains with well developed solution cavities and depressions, some fractures, subrounded, tangential i.e. point to point, grain contacts, well sorted, no cement, good porosity.

Photo. 13. Ellerslie Formation.

Whitemud 15-14-51-25 W4M, @ 4070'.

x450, Ordinary light.

Large rounded quartz grain shows gas and/or liquid filled inclusions and heavy minerals. Smaller grains show secondary silicification coating the grains and reducing the volume of pore space. The grains show long grain contacts and sutures, indicating moderate pressure solution. Also some heavy mineral inclusions in the smaller grains. Fairly good porosity.

Photo. 14. Ellerslie Formation.

Whitemud 15-14-51-25 W4M, @ 4213'.

x72.5, Ordinary light.

Orthoquartzite, fine to medium grained, not very well sorted, subangular to rounded, low sphericity. Secondary silicification causing angularity, long grain boundary contacts and sutured margins, pitted surfaces. No matrix. Fairly good porosity and permeability.

Photo. 11.

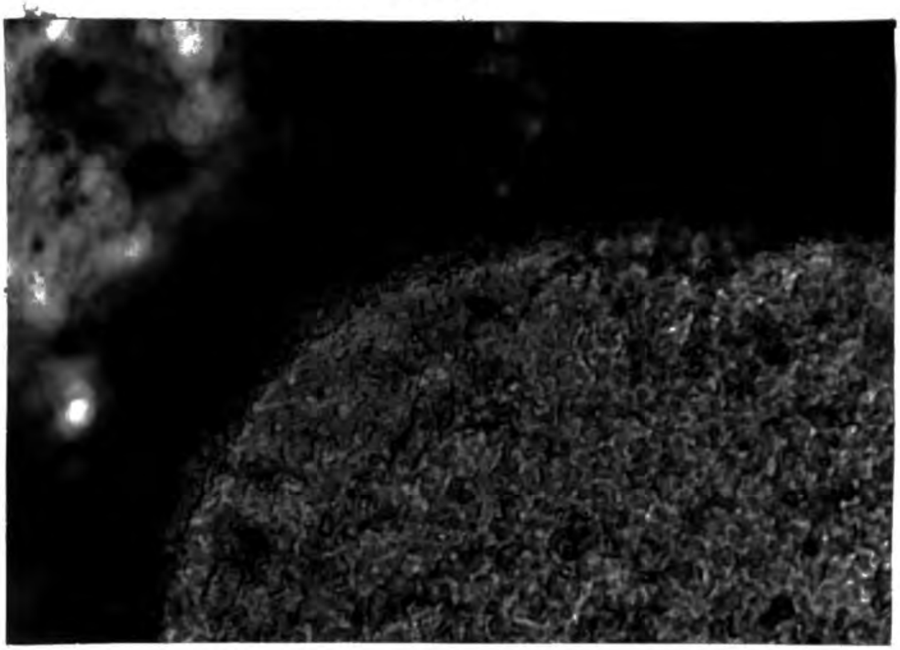
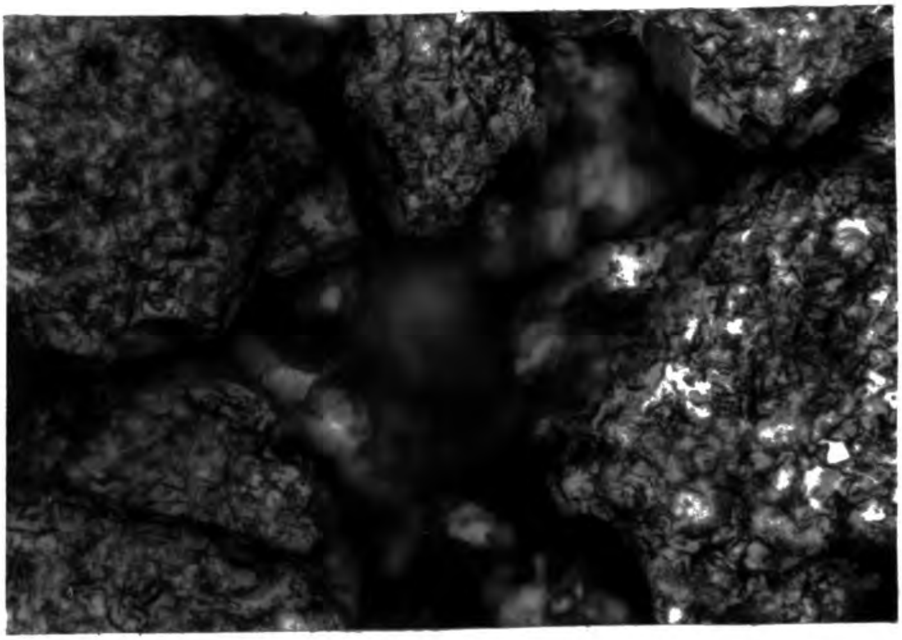


Photo. 12.



Ellerslie Formation, x450, O.L.

Upper: Etched surface of "floating" gain showing good roundness.

Lower: Pitted surfaces, tangential grain contacts, well sorted, no cement, good porosity.

Photo. 13.

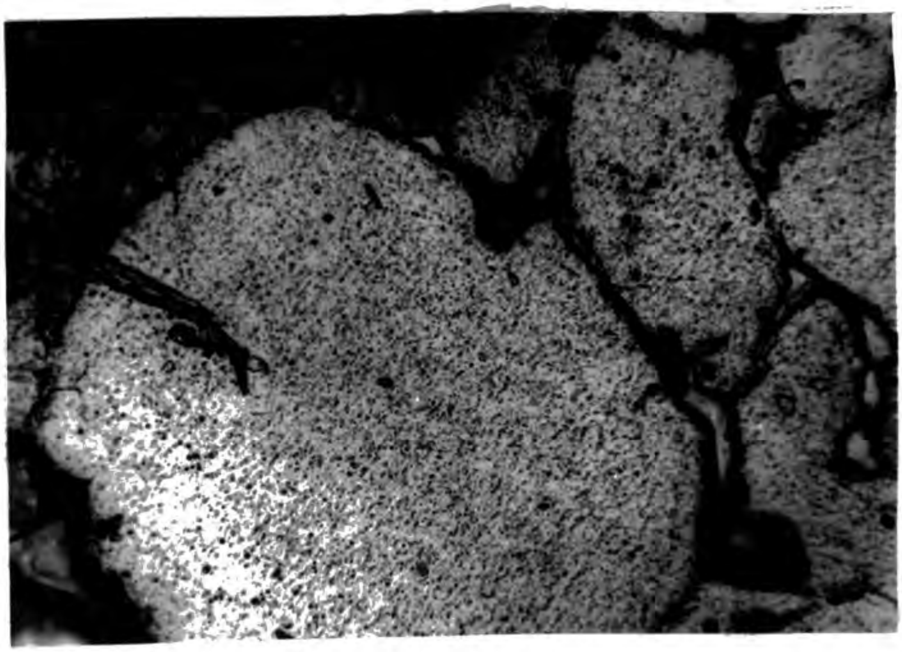
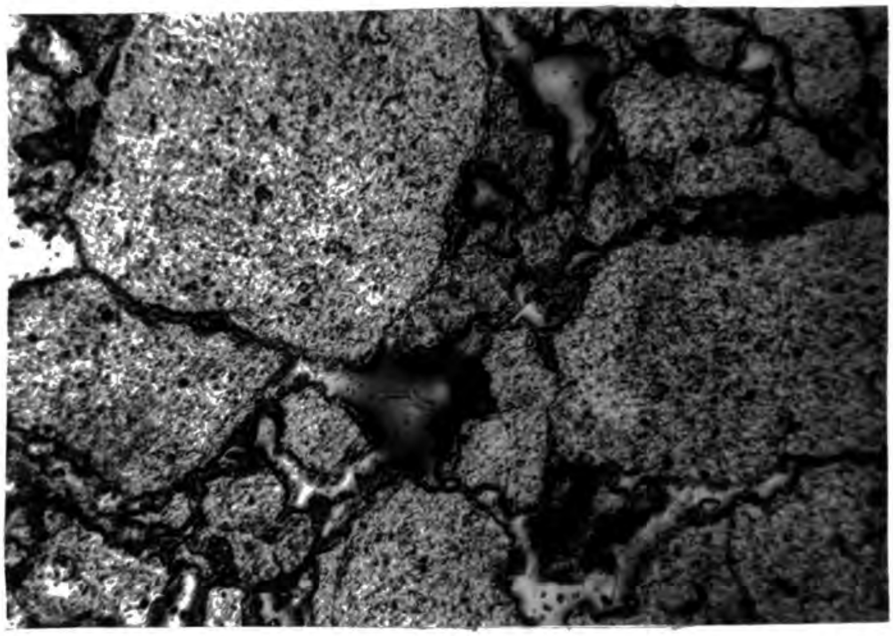


Photo. 14.



Ellerslie Formation, O.L., Quartz grain overgrowths and sutured boundaries due to pressure solution effects. Fairly good porosity.

Upper: = x450. Lower: = x72.5.

Photo. 15. Base of Calcareous Member.

Sprucefield 1-31-60-19 W4M, @ 2380'.

x450, Ordinary light.

Orthoquartzite, medium to coarse grained, rounded, pitted surfaces showing concavo-convex grain contacts and sutured margins as a result of moderate pressure solution. No matrix. Fairly good porosity.

Photo. 16. Ellerslie Formation.

Whitemud 15-14-51-25 W4M, @ 4148'.

x450, Ordinary light.

Pressure solution causing flattened grain contacts and almost complete occlusion of porosity. Pitted surfaces.

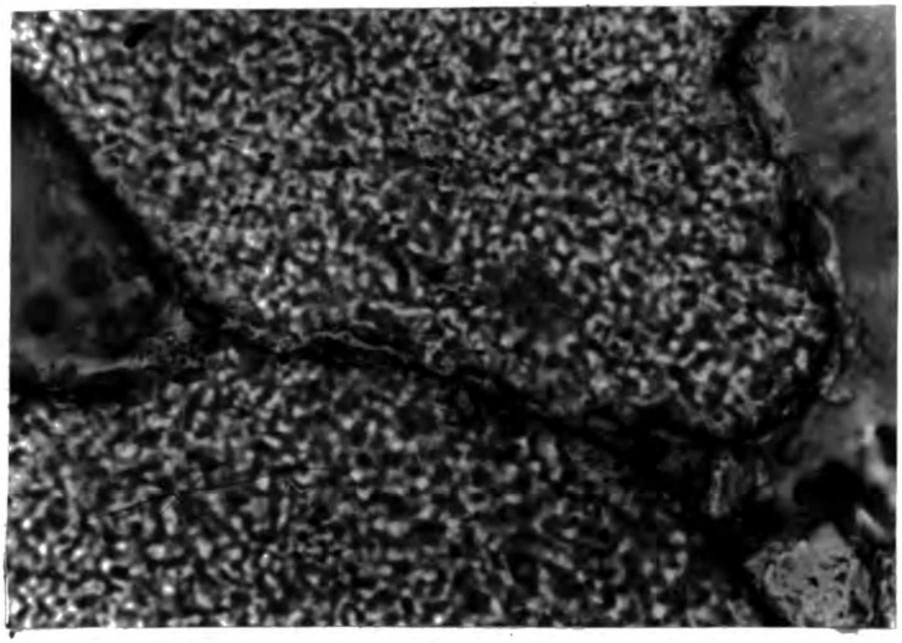
Photo. 17. Ellerslie Formation.

Whitemud 15-14-51-25 W4M, @ 4181'.

x112.5, Ordinary light.

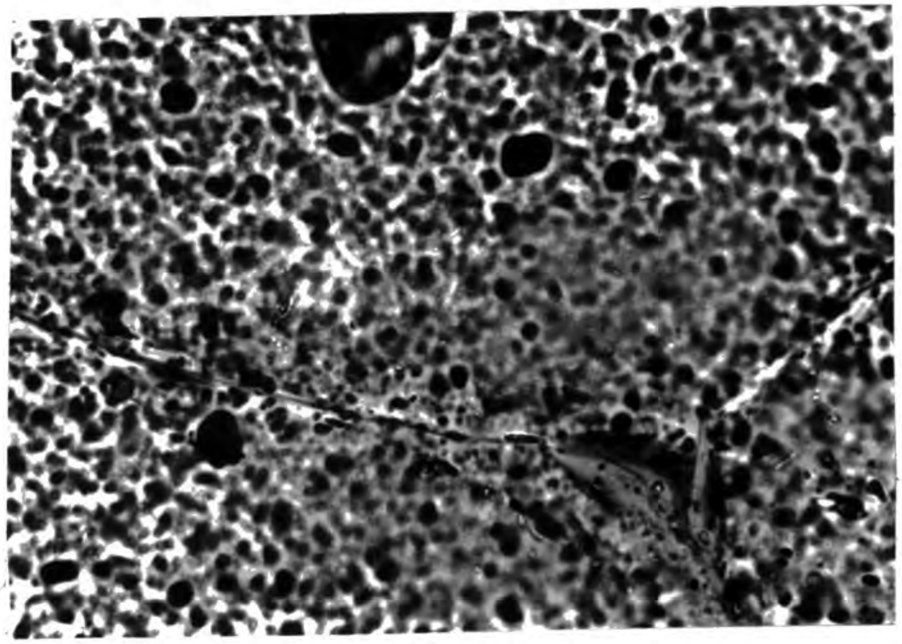
Coarse quartz grain about 2mm. long showing a linear pattern of inclusions. The inclusions are of gas and/or liquids and are aligned parallel to small fractures which are presumably caused by stresses that also cause the grains to show undulose extinction. This grain also shows a pseudo-angularity due to crystallisation of silica dissolved by pressure solution at the point of grain contacts. (cf. Photo. 14).

Photo. 15.



Calcareous Member, x450, O.L., Concavo-convex grain contact and sutured margin.

Photo. 16.



Ellerslie Formation, x450, O.L., Pressure solution effect causing flattening of grain contacts and almost complete occlusion of porosity.

Photo. 18.

Same as Photo. 17, but with central area enlarged to x450.

Photo. 19. Ellerslie Formation.

Whitemud 15-14-51-25 W4M, @ 4213'.

x72.5, Ordinary light.

Orthoquartzite, medium grained, subrounded to rounded, and fine grained angular fragments. Corroded margins, well developed sutured boundaries, concavo-convex grain contacts. Carbonaceous plant remains.

Photo. 20. Ellerslie Formation.

Sprucefield 1-31-60-19 W4M, @ 2440'.

x72.5, Ordinary light.

Protoquartzite, medium sized rounded chert grains with surfaces considerably etched and pitted, concavo-convex grain contacts. Also fine grained angular quartz grains and carbonaceous remnants.

Photo. 21. Wabiskaw Member or Glauconitic Ss.

Sprucefield 1-31-60-19 W4M, @ 2340'.

x72.5, Ordinary light.

Photo. 17.

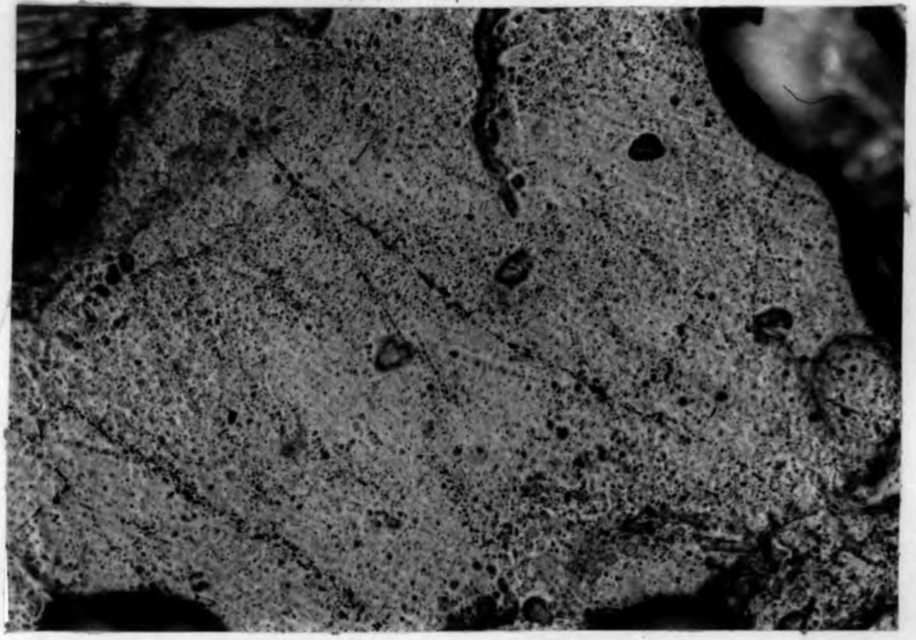
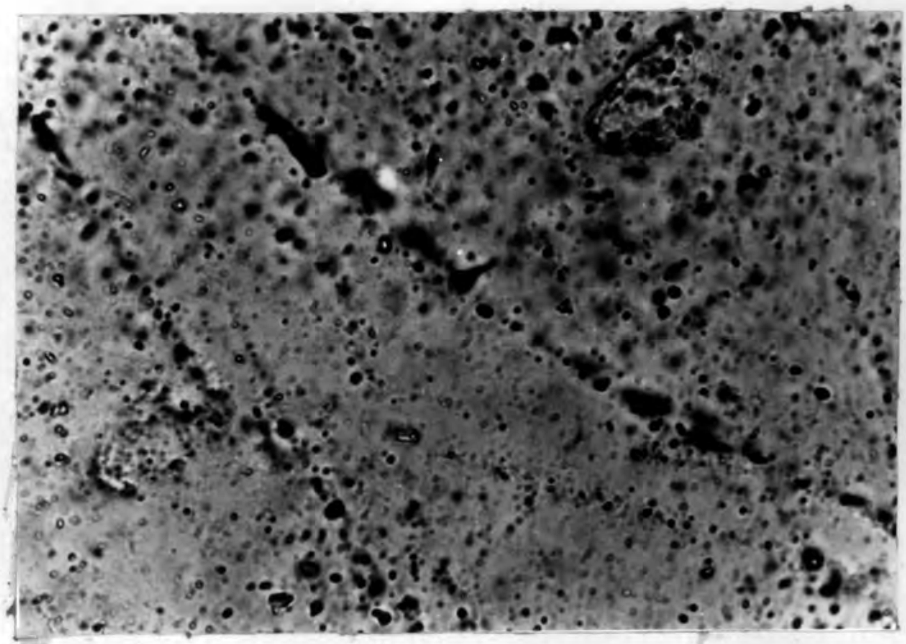


Photo. 18.



Ellerslie Formation, O.L. Linear pattern of inclusions parallel to small fractures.

Upper: = x112.5. Lower: = x450 (central area of Photo. 17).

Photo. 19.

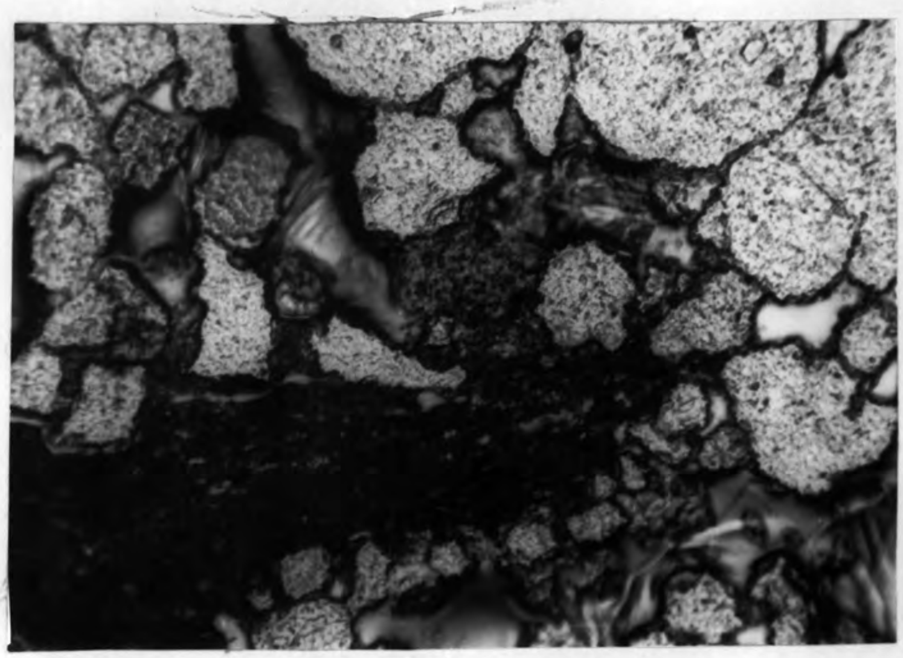
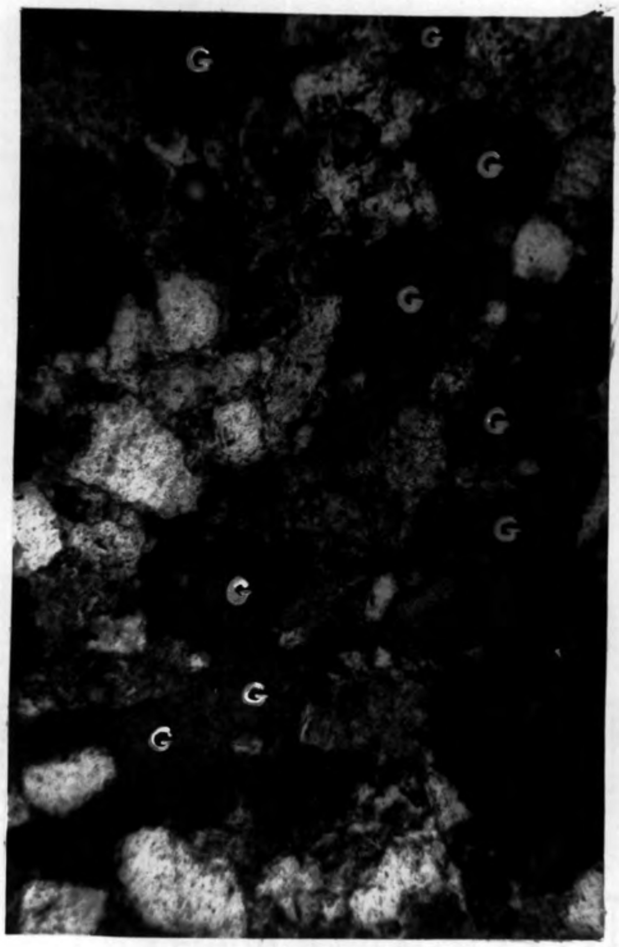


Photo. 20.

Ellerslie Formation, x72.5, O.L. Showing the mixed nature of this sandstone, including plant fragments and porosity.

Photo. 21.



Wabiskaw Member = Glauconitic Sandstone, x72.5, O.L.
Abundant medium grained subrounded glauconite (G).

Photo. 21. (contd)

Glauconite, medium grained, subrounded, pitted and etched surfaces, in protoquartzite, fine grained, subangular, poorly sorted. Clay mineral matrix. Also a few grains of yellow stained potash felspar.

(K/A age determinations on the glauconite in this well indicated 108 million years as the age of the Wabiskaw).

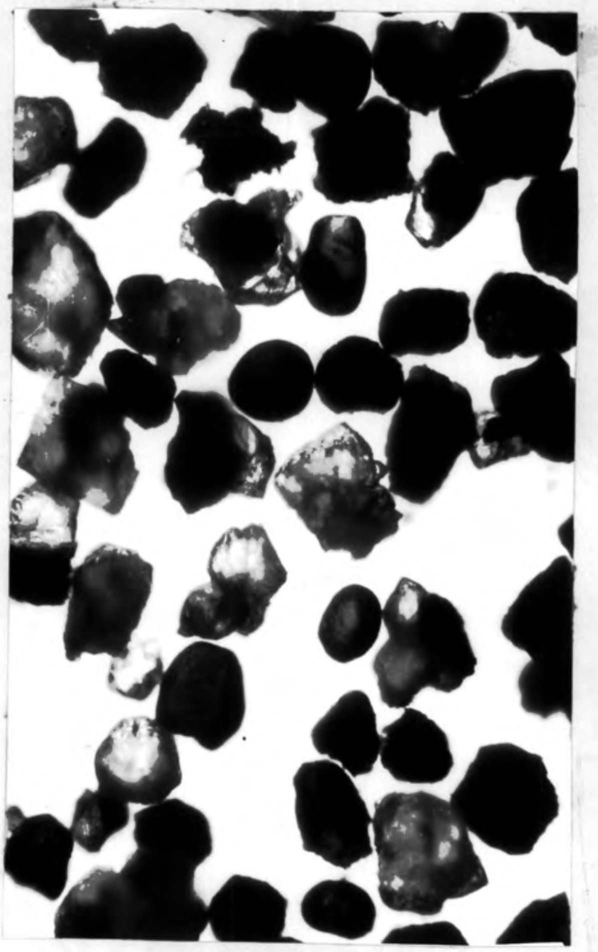
Photo. 22. Ellerslie Sandstone.

Whitemud 15-14-51-25 W4M,

x35, Transmitted light.

Disaggregated grains of Ellerslie Sandstone to show the variations in angularity and roundness, and fair to good sphericity. Angularity may be due to fracturing during the mechanical disaggregation, but this would not be common as the specimen was very friable. It may therefore be pseudo-angularity due to crystallisation of precipitated silica derived by pressure solution, as overgrowths around previously existing grains.

Photo. 22.



Disaggregated Ellerslie Sandstone grains, x35, transmitted light, to show angularity, roundness and sphericity.

CORE PHOTOGRAPHS, BELLSHILL LAKE OILFIELD

Scale: 3½" diameter core.

Photo. 23. (A).

Richfield Flagstaff 10-18, 2931'. Calcareous Member.

Cross-bedding formed by very fine grained truncated sand ripples, having amplitudes of less than one inch. The dark layers are siltstone. These beds are interpreted partly on the basis of contained, smooth shelled ostracods, arenaceous foraminifera, and coaly laminae, as having been deposited in an environment characterised by coastal swamps and estuaries. This type of cross-bedding is formed at the mouths of distributaries and estuaries at the present day.

Photo. 24. (B).

Richfield, Flagstaff 10-18, 2965'. Calcareous Member.

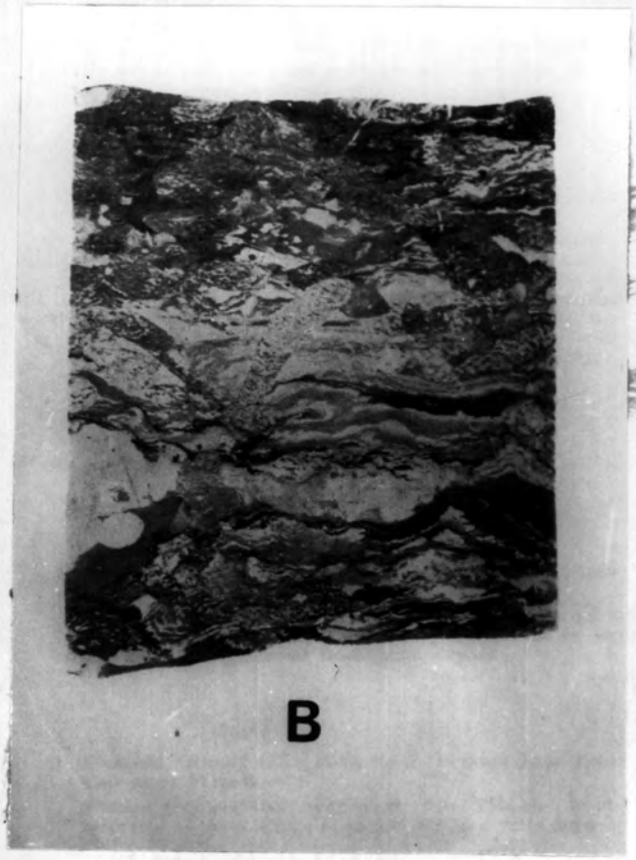
Churned bedding, (=bioturbation) probably caused by mollusc and worm borings. The disturbance of the sediment has almost destroyed the original bedding laminations of alternating fine grained siltstone and sandstone, giving the core a mottled or mixed appearance. These beds are interpreted as having been deposited in an estuary or embayment.

Photo. 23. (A).

A

Calcareous Member, Richfield Flagstaff 10-18, 2931'.
Cross-bedded silty sandstone characteristic of estuaries.

Photo. 24. (B).



Calcareous Member, Richfield Flagstaff 10-18, 2965'. Bioturbation in sandstone and siltstone, practically destroying the original finely laminated bedding.

Photo. 25. (C).

Hudson's Bay, Bellshill Lake 1-33, 2995'. Calcareous Member.

Curved surface of the core showing the broken and distorted bedding believed to have been caused by slumping of laminated fine grained sandstone and siltstone. These cores are interpreted as coming from beds deposited as alluvial sediments on the shores of an estuary. The evidence suggests that these shores consisted of tidal marshes and mud flats cut by the meandering channels of tidal streams.

Photo. 26. (D).

As above, (Photo. 25), but showing the flat sliced surface of the core cut in half.

Photo. 27. (E).

Hudson's Bay, Bellshill Lake 1-21, 3045'. Calcareous Member.

(Figure 3, Cross section 3).

Carbonaceous branching rootlets in a light grey mudstone, seen on a vertical surface of core. This specimen is interpreted as the soil zone of an alluvial flood plain accumulation.

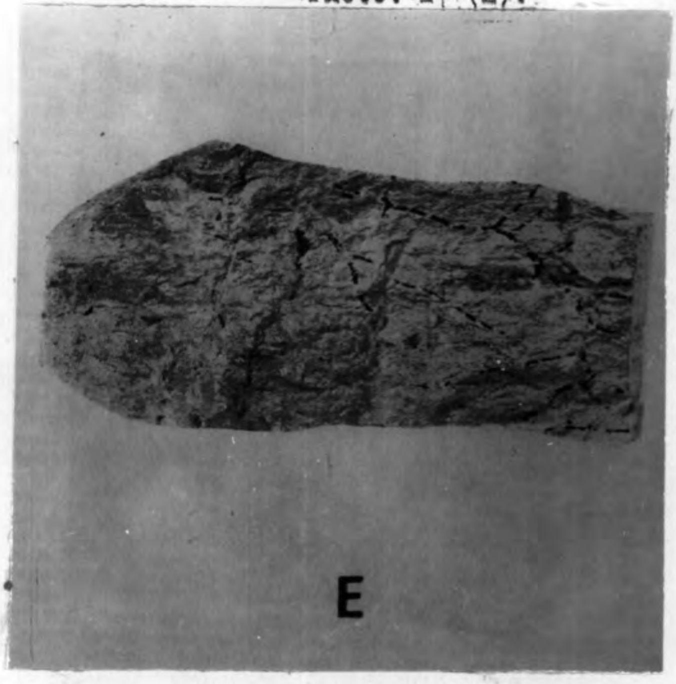
Photo. 25. (C).

Calcareous Member, Hudson's Bay Bellshill Lake 1-33, 2995'. Slumped bedding zone in finely bedded sandstone and siltstone.

Photo. 26. (D).

As Photo. 25, but showing the sliced surface of the core.

Photo. 27 (E).



Calcareous Member, Hudson's Bay Bellshill Lake 1-21, 3045'. Carbonaceous rootlets in light grey mudstone interpreted as a fossil soil zone.

Photo. 28. (F).

Calcareous Member, Richfield Schultz Lake 10-10, 3155'. Mottled grey mudstone with carbonaceous plant roots.

Photo. 28. (F).

Richfield, Schultz Lake 10-10, 3155', Calcareous Member.

(Figure 3, Cross section 3).

Mottled grey mudstone with carbonaceous plant roots. This is a further specimen which is interpreted as the fossil soil of an alluvial flood plain deposit.

Photo. 29. (G).

Hudson's Bay, Schultz Lake 4-15, 3093', Calcareous Member.

(Figure 3, Cross section 3).

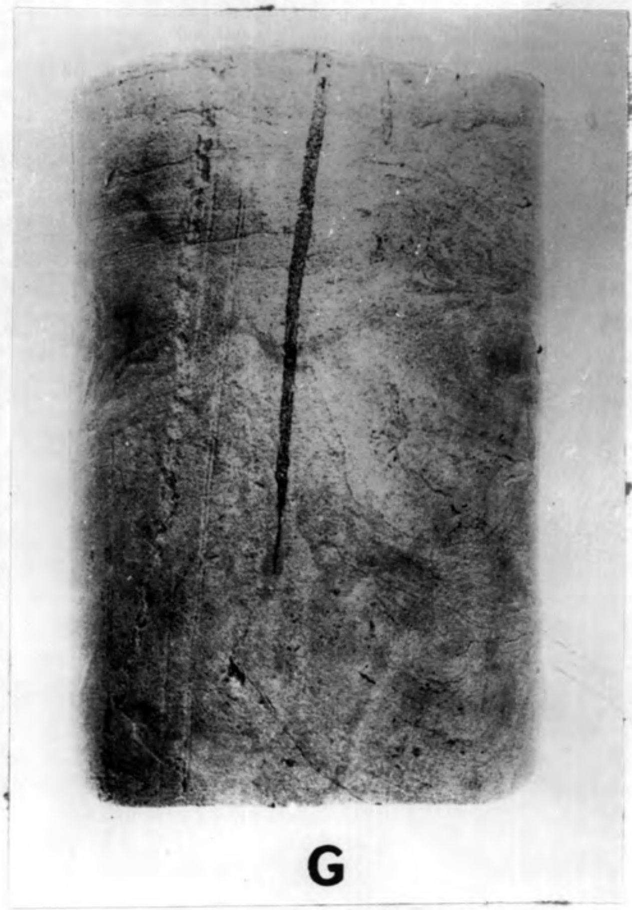
Contorted bedding in siltstone penetrated by an undisturbed carbonaceous plant root. The contortions are interpreted as having been formed by slumping of sediment on the slope of a tidal stream channel. As the root is not disturbed it evidently grew in the slumped sediment. Slumping, in this case, is attributed to hydroplastic (=thixotropic) flow.

Photo. 30. (H).

Richfield, Flagstaff 10-18, 3136', Ellerslie Sandstone.

Inclined bedding in a coarse grained quartzose sandstone. This inclined bedding is the foreset bedding of a large ripple having a considerable amplitude. The ripple is interpreted as a river deposit. The coarse texture of the rock can be seen even from the core photograph. It is almost conglomeratic at the bottom and gives the impression of being very friable, with good porosity, which it is.

Photo. 29. (G).



Calcareous Member, Hudson's Bay Schultz Lake 4-15, 3093'. An undisturbed plant root penetrating contorted bedded siltstone.

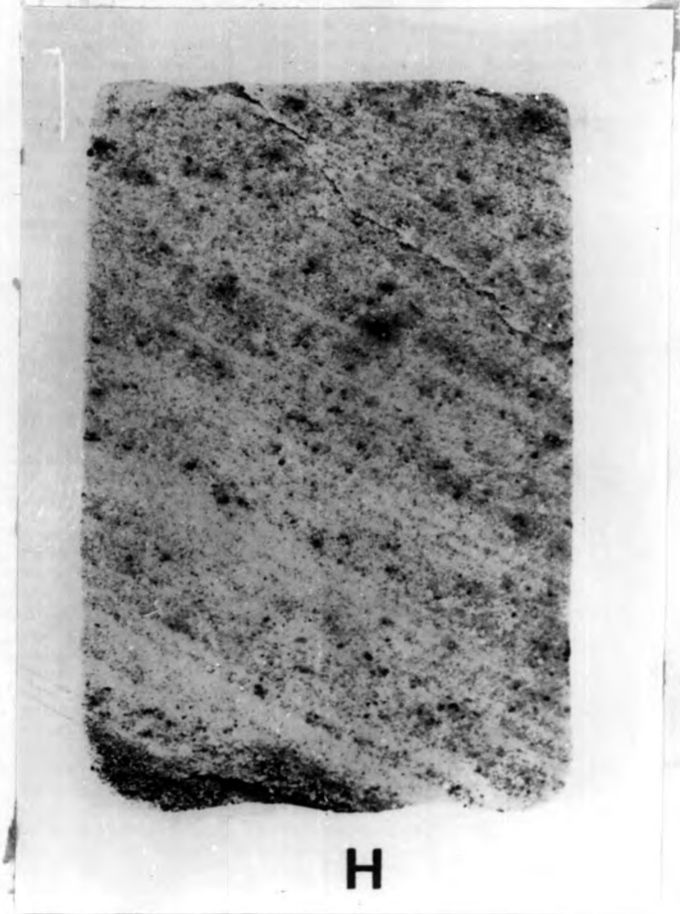
Photo. 30. (H). (contd)

This quartzose cross bedded sandstone rests unconformably on Palaeozoic carbonates, and forms the reservoir of the Bellshill Lake oilfield, with its considerable water drive.

Photo. 31. (I).

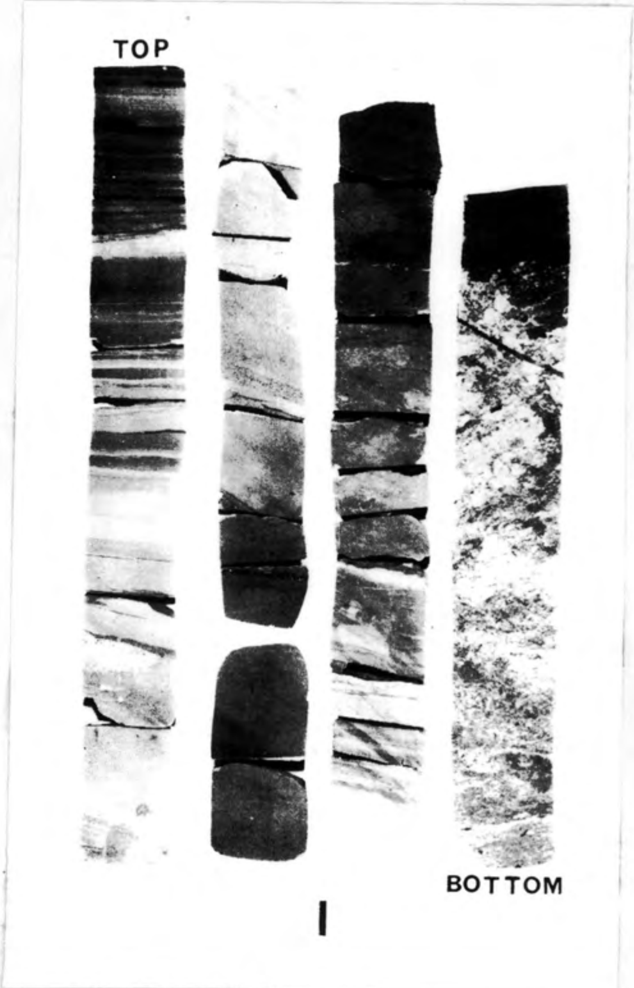
Core photographed, still wet, as it was laid out in boxes. Note that contacts, depths, and interesting features, could be marked on such a photograph as a permanent record for inclusion with the core descriptions in a report, or in company files.

Photo. 30. (H).



Ellerslie Sandstone, Richfield Flagstaff 10-18, 3136'.
Foreset bedding in a coarse grained quartzose sandstone.

Photo. 31. (I).



Core photographed, still wet, as it was laid out in boxes.

CORE DESCRIPTIONS

From typical Bellshill Lake boreholes, Lower Mannville.

1. RICHFIELD SCHULTZ LAKE No. 9-10-41-12 W4M.

Elevation 2477' KB. Diamond Core.

CORE 1. 3155'-3175' 20' cut 18'1" recovery.

9'4"	SHALE medium grey, micaceous, carbonaceous, silty with SILTSTONE light grey, to light brownish grey, mainly quartz with some authigenic overgrowth, micaceous, carbonaceous, in laminae and very thin beds which have been considerably disrupted physically and organically. (Photo. 25).
4'9"	SHALE medium to dark grey with slight brownish cast, silty, carbonaceous, with abundant small carbonised rootlets, stems etc., micromicaceous, pyritic, scattered fish scales.
4'0"	SHALE medium to dark grey, very silty, carbonaceous, micromicaceous and SILTSTONE light grey to light brownish grey, carbonaceous, micromicaceous in irregular laminae and very thin beds, pyritic. Much broken carbonised plant material occurs especially along shale breaks.

CORE 2. 3175'-3195' 20' cut 19'5" recovery.

2'5" as at base of core 1.

17'0" SHALE medium to dark grey, carbonaceous, silty, micromicaceous, in part irregularly laminated with

SILTSTONE to

SANDSTONE very fine grained, light grey to light brownish grey, carbonaceous, micromicaceous, calcareous in part, sideritic (in part detrital siderite grains), pyritic. Much broken, carbonised and in part pyritised plant material occurs along bedding planes. Occasional beds upto 6" composed of fine lentils of CALCARENITE creamy grey to yellowish brown, coarse grained, pyritic, sideritic.

CORE 3. 3195'-3210' 15' cut 13'8" recovery.

17'8" SHALE medium to dark grey, silty, micaceous, carbonaceous to coaly with interbedded

SILTSTONE to

SANDSTONE very fine grain, light grey to brownish grey, carbonaceous, calcareous in part, pyritic.

CORE 4. 3210'-3220' 10' cut 5'+ recovery.

(box 1 of two missing).

basal 5' SHALE dark grey with slight greenish cast, slightly silty in part, pyritic (cubes, nodules and associated with organic material). Carbonised plant remains chitinous remnants of mollusc shells, and other small poorly preserved fossil fragments are common as well as a few poorly preserved smooth shelled ostracods.

CORE 5. 3220-3232' 12' cut 9'8" recovery.

9'8" SHALE dark grey, slightly silty in part, carbonaceous with much carbonised plant material along bedding planes, interlaminated with

SILTSTONE light grey, calcareous in part, pyritic (nodules may be fossil replacements) and a few scattered, poorly preserved mollusc fragments.

CORE 6. 3232'-3238' 6' cut.

Missing.

CORE 7. 3238'-3263' 25' cut 13'7"+ recovery.

(Boxes 1 and 4 missing. First interval starts at approximately 3243' and second at 3258').

(3243') 1'9" SHALE olive green, soft, bentonitic, pyritic with coaly flecks and streaks, considerably sheared and cut by veins of light greenish-grey calcite.

7'10" SHALE light to medium grey, silty, carbonaceous, pyritic, hard blocky with minor slickensiding.

(3258') 4'0" SHALE medium grey with fine darker (bitumen?) mottling, micromicaceous, carbonaceous, very slightly silty, pyritic, slickensides common at varying attitudes. Scattered chitinous material may have been mollusc shells.

2. RICHFIELD BELLSHILL LAKE No. 15-20-41-12 W4M.

Elevation 2295' KB. Diamond core.

<u>CORE 1</u>. 2959'-2994' 35' cut 28'3" recovery.

7'6" SHALE medium to light grey with minor dark bands at the top of the interval, micaceous to micromicaceous, silty, carbonaceous, with much carbonised and pyritised plant material (stems and roots etc). Disseminated and finely nodular pyrite is common, minor slickensiding and brecciation common through-out.

5'10" SHALE as above, with fine irregular laminae.

SANDSTONE very fine grained to

SILTSTONE light greyish brown, quartzose with abundant overgrowths becoming more sandy towards the base.

14'11" SANDSTONE light grey to light greyish brown, very fine grained, quartzose with much authigenic overgrowth subangular to subrounded micaceous in part, and abundant irregular laminae.

SHALE dark grey, micaceous, carbonaceous, silty, becoming predominant in bands upto 7". Bedding is highly disrupted by animal burrows (Photo. 24). Oil staining scattered through-out where lack of shaly laminae creates good intergranular porosity.

CORE 2. 2994'-2999' 5' cut 4'4" recovery.

4'4" SANDSTONE as in core 1. with shaly laminae becoming less common resulting in overall increase in porosity and oil staining.

ECONOMIC GEOLOGY OF PETROLEUM AND NATURAL GAS

In the western Canadian Plains numerous oil and gas accumulations occur in Lower Mannville sandstones. The reservoirs are primarily stratigraphic traps formed by clean, well sorted and porous sandstones grading laterally into shale or argillaceous sandstone. These facies changes, in many cases, are related to the topography of the sub-Cretaceous erosional surface. Combined stratigraphic and structural traps are important, particularly in central Alberta where differential compaction over the erosional highs has produced structural traps in clean sandstones which appear to owe their lithologic character to reworking and winnowing of the sands in these bars at the time of their deposition.

Exploration has been carried on in western Canada for over sixty years but results were disappointing until 1947 when oil was discovered in the Devonian Leduc reef complexes near Edmonton, Alberta. Since 1953 petroleum has been the leading mineral in dollar value produced in Canada. In 1965 output of all liquid hydrocarbons from Western Canada averaged 919,000 barrels daily (Latus 1966). In addition to this conventional well head production, plant is nearing completion for the large scale mining and processing of the Lower Cretaceous Athabasca Oil Sands, near McMurray in northern Alberta. These sands contain the largest known oil reserves in the world; estimates of oil in place range as high as 710 billion barrels.

During the past decade, natural gas reserves have increased enormously to meet not only an expanded Canadian market, but also to supply several areas in the United States. Much of the gas requires processing to remove the lighter liquid hydrocarbons and sulphur but these are also of economic value, a total of 1,589,000 tons of sulphur being produced in 1965. The total gas produced in Western Canada for all markets in 1965 was 1,315 billion cubic feet (1315×10^9 cubic feet) (Latus 1966). Domestic sales amounted to 1.1 billion cubic feet daily and exports to 0.9 billion cubic feet daily.

Alberts is by far the richest province in Canada in respect to reserves of oil and gas, having 82.5% ultimately recoverable oil reserves and 84.2% ultimately marketable gas reserves. The Palaeozoic reservoirs, predominantly carbonates, contain 71% of the total Western Canadian Basin oil reserves, comprising 57% Devonian and 14% Carboniferous formations. The Upper Cretaceous sandstones are second comprising 18.0% and the Lower Cretaceous sandstones fourth with 4.4%. For natural gas the Carboniferous formations lead with 32.3% followed by the Devonian 31.0%, Lower Cretaceous 21.2% and the Upper Cretaceous 6.6%. Total initial in-place crude oil in the Mannville Group (excluding the Athabasca Oil Sands) is nearly 1,000 million barrels and initial in-place natural gas reserves amount to nearly 8,000 billion cubic feet.

Grouping by size of the oil and gas pools in western Canada produces interesting results. Of the 292 individual oil pools in western Canada over 91% have less than 25 million barrels of recoverable oil. Only three pools have more than 400 million barrels of recoverable oil viz. Swan Hills and Redwater, both Upper Devonian reef complexes, and Pembina in the Upper Cretaceous Cardium sandstones. There are a total of 647 gas pools in western Canada of which 434 (67%) have reserves less than 25 billion cubic feet. The Medicine Hat field in southeast Alberta is the largest with over 1700 billion cubic feet of ultimately marketable gas in the Upper Cretaceous Medicine Hat sandstone. (Brodylo 1964).

FORMATION FLUIDS

Geochemistry

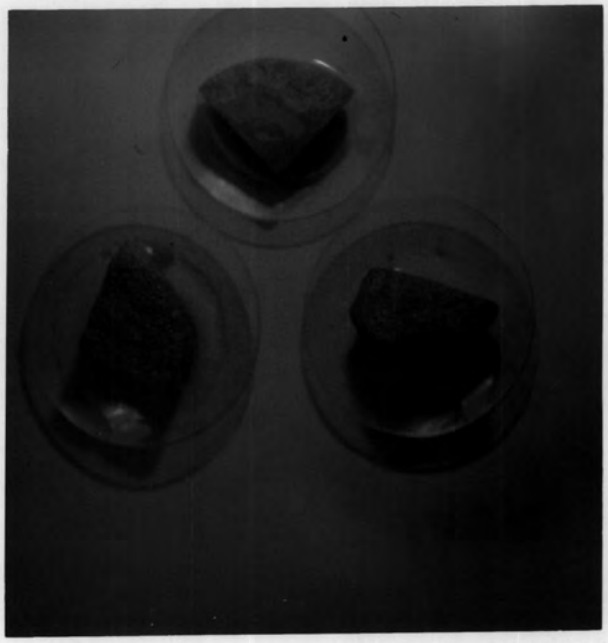
It is generally recognised now that crude oil originates from the selective accumulation of unmodified and relatively slightly modified plant and animal lipids, probably largely derived from phyto-plankton, with the process probably aided by bacterial transformations (Meinschein 1959). The distribution of the individual hydrocarbon compounds in western Canadian crude oils has not been determined, although Hodgson and Baker (1959) have noted the variations of the major groups - asphaltenes, resins and oily constituents, in selected crude oils from a number of fields. There appears to be a close relationship between the content of oily constituents and the °A.P.I. gravity of the crude oil. The relationship of weight per cent carbon residue and viscosity to °A.P.I. gravity for Alberta crude oils was illustrated by Hitchon and Shaw (1960). Data on the fluorescence of crude oils under ultraviolet radiation have been compiled by Rieker (1962), who suggested the use of fluoranalysis to determine the direction and distance of crude oil migration.

Next to hydrocarbon compounds, sulphur in the form of unmodified and modified compounds derived from the original organic material, is the most important constituent of crude oils. The sulphur content of 1605 western Canadian crude oils determined by Hitchon ranged from less than 0.01% in the very light oils to 10.04%

in a heavy oil (13.2°A.P.I.) from the Ellerslie Formation at the Erskine field. Nitrogen and oxygen have been determined only for the McMurray Formation (Pasternack and Clark 1951) but trace metals have been determined for a wider variety of crude oils (Hodgson 1954, Hodgson and Baker 1959).

Differences in composition of crude oil in oil fields of western Canada are apparent. Several factors must be considered in any explanation of these differences. The pre-Cretaceous crude oils are entrapped predominantly in carbonate rocks and the Cretaceous crude oils in arenaceous beds. Also, both pre-Mannville and post-Mannville crude oils have essentially similar properties. Thus neither the gross lithology of the reservoir rocks nor the apparent age of the crude oil seem reasonable causes for the variations observed, (Table 1). Both temperature and pressure vary directly with depth of burial and consideration of the regional variations in crude oil composition as shown by Hitchon (1961) indicates no obvious relationship. There does however, appear to be a relationship between the observed trends in composition and the environment of deposition. The effect of depositional environment of the sediments upon the composition and volume of the crude oil generated is described by Hitchon (1964) as the "basin-shelf" control concept. Briefly, this postulates that in the deeper basin shale facies anaerobic conditions generally prevail and the organic material preserved is high in paraffinic content. In the shallow shelf facies rapid sedimentation preserves more of the

Photo. 32.



Fluorescence shown by oil staining core specimens.

oxygen, nitrogen and sulphur compounds of the organic material and the resulting crude oils are relatively high in asphaltic and low in paraffinic hydrocarbons. Study of the relationship of the environmental factor in the control of crude oil composition indicates that the position of the Lower Cretaceous oil sand deposits on the broad continental margin, which occupied practically all of Alberta in early Cretaceous time, is reflected in the asphaltic nature or the crude oils.

Hitchon's analyses show that the crude oil in the Mannville Group of Lower Cretaceous age is distinct from that in all other formations in the western Canadian Sedimentary Basin. A summary of these chief properties follows.

TABLE 1

	Mannville Group	All Others
Gravity of crude oil °A.P.I. :-	Range 13°-38° Average 22°	35°-40°
Weight per cent sulphur :-	Range 0.2-3.6 Average 2.2	<0.69%
Volume per cent residuum :-	Range 20-57 Average 37	<26.5%
Carbon residue of residuum :-	Range 0.2-18 Average 12	<10%

The Mannville oils are further characterised by their high asphaltene-aromatic content. Regional variations in the A.P.I. gravity of crude oils from the Ellerslie Formation indicate a tendency for the heavier crude oils to be associated with the near shore facies. This is also illustrated by other horizons in the Mannville group of Hitchon's "basin-shelf' concept (1964).

No distinctive pattern is evident from a study of the geochemistry of natural gas from the productive formations in western Canada whether the natural gas is alone in the reservoir or associated with crude oil. The natural gas is predominantly methane, total hydrocarbons generally being over 95%, together with varying proportions of non-combustibles such as nitrogen, carbon dioxide and hydrogen sulphide. As far as the Lower Mannville is concerned the weighted average value of nitrogen is 3% with a range from zero to 12%; the weighted average value of carbon dioxide is 1.5% with a range from zero to 12%; while the weighted average of hydrogen sulphide is 0.25% with a range from zero to 10%; rarely over 1% and most commonly absent from Mannville Group strata. The proportion of these gases increases with the age of the reservoir. At Thompson Lake and Choice oil fields (Figure 11) in east-central Alberta, natural gases in the Ellerslie Formation contain up to 4.3% hydrogen sulphide, associated with moderately large contents of carbon dioxide (9.6 to 11%). A pre-Cretaceous source for these acid gases is suggested, migration having occurred from the Palaeozoic strata below the sub-Cretaceous unconformity.

The formation waters found in the Mannville Group strata have previously been involved in atmospheric circulation and would be regarded by White, Hem and Waring (1963) in their genetic classification of subsurface waters as falling into the class of connate or fossil waters of marine origin. It is generally accepted that formation waters represent post-depositionally modified water that was originally trapped in the sediments. In many cases this trapped water must originally have had a composition similar to present day sea water since there is reason to believe that the overall composition of oceanic water has remained fairly constant at least since Cambrian times (Rubey 1959). However some sediments were deposited under brackish or fresh water conditions but the original chemical composition of the formation water is masked due to contamination and the chemical characteristics of formation waters are quite similar to those of present day sea water. Differences in chemical reaction with surrounding rocks, dilution with percolating ground water or bacterial transformations. In general there is an increase in the concentration of dissolved solids in formation waters with depth and increasing age of the strata unless there has been dilution by percolating, meteoric, near surface ground water. It may be reasoned then that in many cases the water, but not the entire quantity of dissolved salts, originated from the water in which the sediments were initially deposited.

It is believed that only the chloride content reflects the true degree of concentration or dilution of the formation water, because all other components are prone to alteration relative to the original sea water, by such processes as base-exchange or bacterial transformation. Dilution or concentration of the original sea water is accompanied by these phenomena and thus the only major source of alteration of the relative chloride content will be by contamination with other formation waters whose relative ratio of chloride to other components has been altered, or by solution of halite deposits.

TABLE 2:- Frequency per cent occurrence of total solids (calculated) and individual components in western Canadian formation waters in relation to their respective contents in present day sea-water. (After Hitchon 1964)

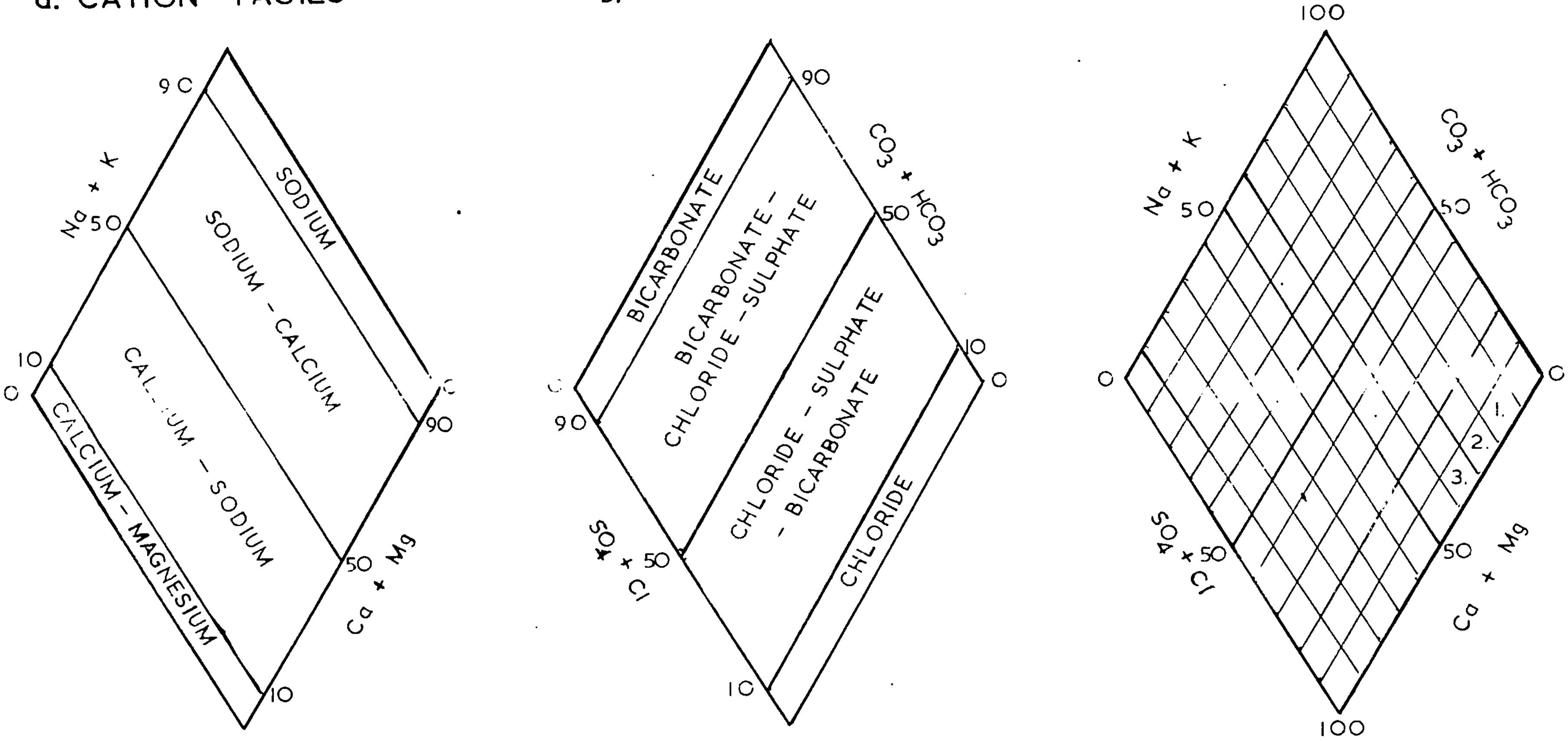
Component	Frequency Per Cent Occurrence			
	$<{}^{1}/_{10}$	<1	>10	Sea Water Content (mg./litre)
Total Solids (Calculated)	3.84	40.49	0.10	34,482
Chloride	11.15	40.65	0.18	18,980
Sodium	4.33	38.71	0.07	10,551
Sulphate	39.29	85.78	0.01	2.649
Magnesium	31.18	77.00	0.20	1,272
Calcium	n.d.	33.37	27.62	400
Bicarbonate	n.d.	5.93	22.26	140

n.d. = not determined

Back hydrochemical facies diagrams are presented (Figure 7). The majority of the water analyses used to compile the chloride concentration trends for the Mannville Group illustrated are for samples from the Ellerslie Formation. Chloride concentrations are essentially similar in formation waters from the Ostracod Member and the Glauconitic Sandstone. The former is essentially a fluvial deposit, the latter passing through brackish to definitely marine. This confirms the contamination of low salinity connate water by ion migration from more saline formation water. In east-central Alberta there is a high salinity area in the Lloydminster region (Twp. 45 Rge. 6 W4M and north-east) due mainly to an abundance of data from the Wainwright Sandstone (cf. Correlation Chart, Figure 3) where the formation waters are more saline than those in the underlying basal Mannville strata. Comparison of isochlor maps of the Mannville Group (Hitchon 1964) with the sand to shale ratio map of the Ellerslie Formation indicates that there is control of the salinity pattern by gross lithofacies changes. Chloride concentrations greater than 18,980 mg./litre (the chloride content of present day sea-water) are associated with stratigraphic sections with less than 35% sand. Throughout Alberta the salinity pattern is apparently related and controlled by the movement of formation waters across the sub-Cretaceous unconformity and it has been demonstrated by means of potentiometric-surface maps (Hitchon 1963) that there is free fluid connection across the unconformity. Also formation fluid movement

FIGURE 7.

BACK HYDROCHEMICAL FACIES DIAGRAMS



a. CATION FACIES

b. ANION FACIES

c.

c. To indicate the variation in composition of the formation waters above **and** below the sub-Cretaceous Unconformity. 1. Mannville and Upper Devonian, 2. Middle Devonian, 3. Lower Devonian.

in proximity to the unconformity is in a north-easterly direction and through whichever strata offers the least resistance to migration i.e. those with the highest permeability.

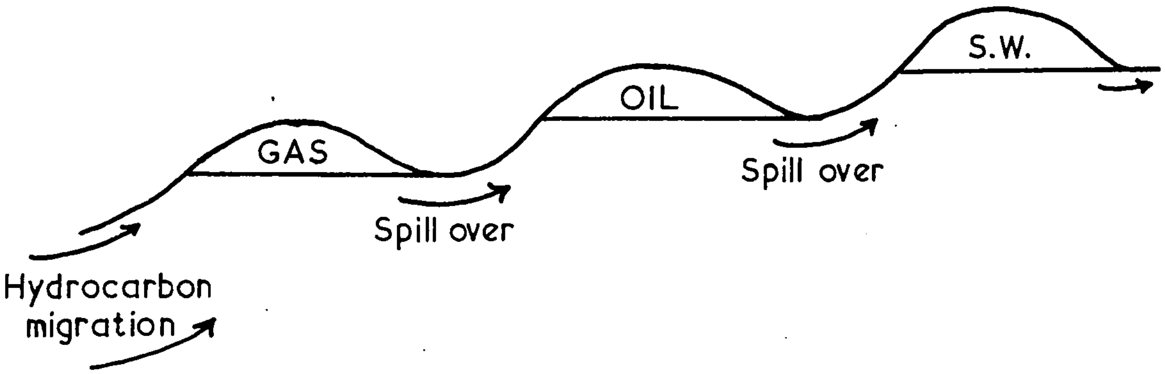
MIGRATION

Migration is the movement of hydrocarbons from source beds to reservoir rocks in sufficient volumes to be commercially exploitable. It is far from being as straight forward as oil floating on water and being trapped beneath a dome shaped impermeable layer. The basic requirement for oil migration in a water wet porous reservoir is that the capillary pressure of the oil-water interface exceed the displacement pressure of the larger openings or capillaries between the pores. For any specific combination of oil, water and sand pores, the displacement pressure is a constant value. On the other hand, the capillary pressure is dependent upon buoyancy and hydrodynamic forces and the length of continuity of the oil phase. Wherever these forces are sufficient to cause the capillary pressure to exceed the displacement pressure, the oil-water interface will enter and pass through the pore-connecting capillaries and oil migration results.

Studies of the hydrodynamics, hydraulics, porosity and permeability have been made by petroleum engineers, geologists, hydrologists and chemists in an endeavour to understand this phenonemon (Hubbert 1953; Hitchon 1960, 1963; Hodgson et al 1959; Weeks 1961). The anomalous relationships of gas, oil and salt water in different structures at the same horizon and the presence of connate salt water in an apparently perfectly good prospecting area have all been difficulties to discern.

Gussow (1954) proposed the principle of Differential Entrapment to explain these so-called anomalous occurrences of oil and gas in contiguous structures. The Western Canadian Sedimentary Basin is an excellent example of this phenomenon which, in essence, is that during migration natural gas passes through the rock pores faster than oil, due to its volatility and viscosity respectively. It is therefore trapped in the lower structural traps and completely fills these, causing the oil to migrate further up-dip to become trapped. Thus, in a porous formation contorted into a series of structural traps, hypothetically, and in practise, salt water will be found in the highest traps, oil in the middle ones and natural gas in those lowest down dip.

Figure 9.



Sketch to illustrate the Principle of Anomalous or Differential Entrapment.

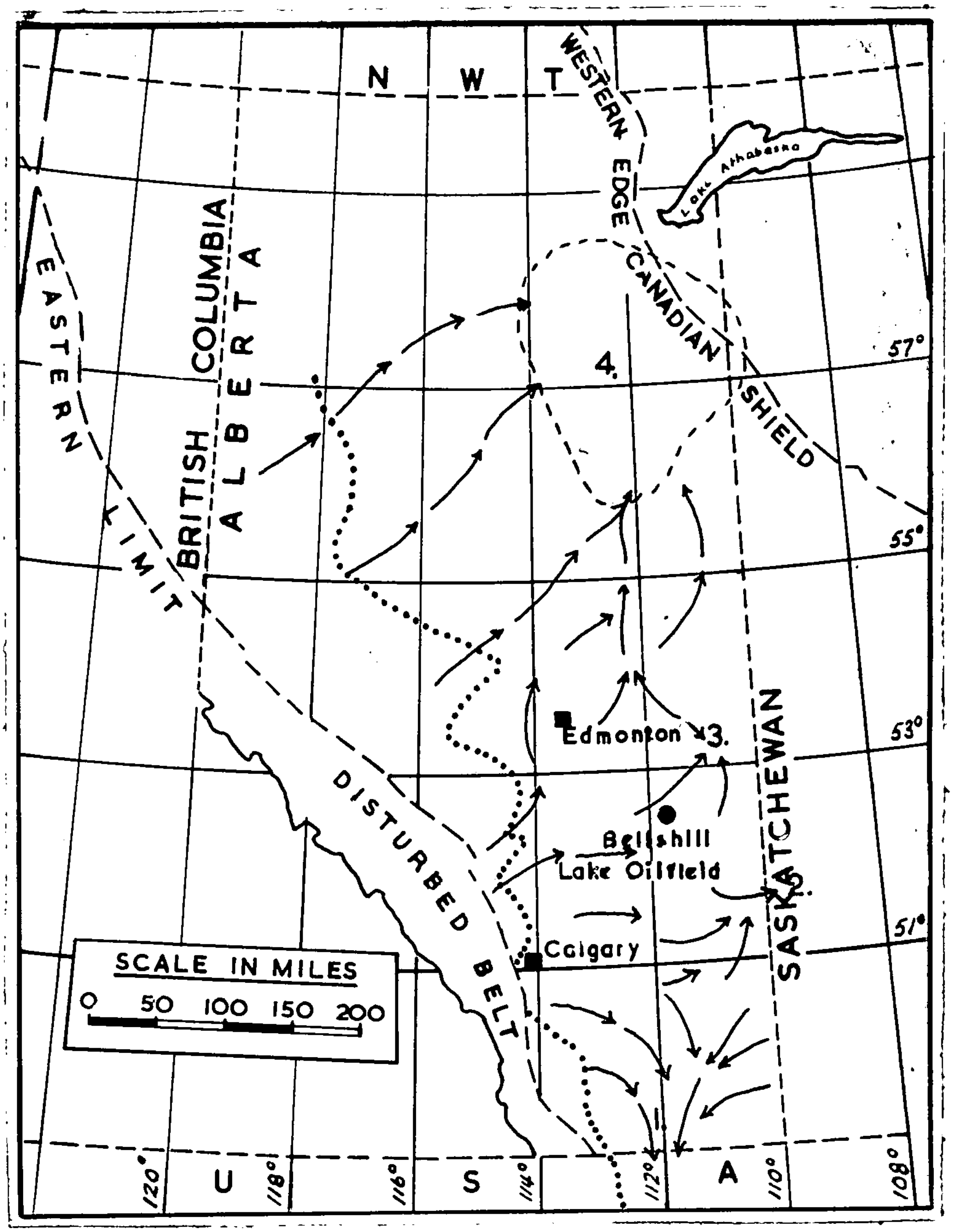


Figure 8 . Migration Paths in the sub-Cretaceous Unconformity Zone.

1. Sweetgrass Arch. 2. Colleville-Smiley.

3. Wainwright-Lloydminster. 4. Athabasca Oil Sands.

.... Updip limit of gas flushing in the Basal Cretaceous. (gas only to west, oil to east).

Gussow further indicates that migration occurs along definite paths as "streams" or "rivulets" and traps located along these migration paths will be filled with hydrocarbon, those which are not will remain loaded with water (Figure 9). The rate of movement of the fluids is a function of the hydrostatic pressure and the permeability. With differential compaction or regional isostatic subsidence in geosynclinal basins a gradually increasing differential pressure due to regional dip or tilt will result. Lateral up-dip movement of the hydrocarbons begins only when the regional dip is sufficient to overcome capillary attraction and friction in the carrier beds.

The predominant tendency is for oil and gas to move updip, the migration path being normal to the structure contours, always seeking the highest spill point. At first globules of oil coalesce to form droplets and these merge to form slugs and the slugs join together to form patches, the patches start to flow in rivulets and these join together in streams and finally "rivers" of oil migrate undip along well established migration paths. All this takes place on the underside of an impermeability barrier, the converse of surface drainage, like the droplets of rain on a car windscreen.

This established migration path will have its local tributory streams and will unite with other larger branches. The path will be generally up dip, out of a basin and on reaching an anticlinal trap, filling it up to the level of the spill point, only to escape in the direction of this spill point. It is rarely in a straight line, (see Gussow (1954) on the Bonnie Glen-Wizard Lake Trend of Alberta). The line of the path is directed by very local changes in porosity and permeability and these may cause perfectly good potential reservoirs to be filled by connate water because they are isolated by downdip lenses of impermeability, deflecting the direction of the migration path.

This lateral movement of hydrocarbons as streams in the carrier beds to their final position of entrapment, is known as secondary migration. It may closely follow primary migration i.e. normal to the regional strike, or tens of millions of years may elapse before lateral or secondary migration occurs. Later spilling due to further regional tilt and decantation, or to expansion of a gascap, is known as remigration (Gussow 1954, page 822).

When the supply basin is exhausted, secondary migration will cease and the reservoir fluids will come to rest. It should be remembered that oil and gas are closely associated, the amount of gas dissolved in the oil or the amount of oil becoming volatile, varies with the temperature and pressure. Thus, if the area of entrapment is subjected to deeper burial, the gas in reservoirs having an oil column and a gas cap, will go partially or completely into solution in the oil, increasing the gas-oil ratio. The size of the gas cap will also be further reduced due to compression of the remaining gas in the gas cap. As a result, the oil-water interface will no longer coincide with the level of the spill point but will be at a higher elevation, making this an effective trap for hydrocarbon once more. Reservoirs filled with oil only will remain unchanged, except that it will be undersaturated in respect of the gas-oil ratio.

The principle of differential entrapment is based on the assumption that oil and gas migrate over great distances, and that adequate source beds occur in a large down dip supply basin. No doubt source beds within an individual structure will contribute hydrocarbons, but local sources are not considered adequate to form commercial accumulations.

As far as the Western Canadian Sedimentary Basin is concerned, and the Lower Mannville in particular, this fits acceptably into the conditions of the differential entrapment proposed. The migration path map (Figure 8) demarcates the updip limit of gas flushing in the basal Cretaceous strata, which contains gas accumulations only on the west, but oil and gas to the east. Hydrocarbon source beds are found in the subcropping Palaeozoic and Mesozoic rocks e.g. the Devonian Ireton Green Shale, the Mississippian Banff Bituminous Shale, and in the Jurassic. Hydrostatic pressure in the Plains region of the Basin and tectonism in the Rocky Mountain Trench are adequate mechanisms to squeeze out the hydrocarbon, and all the sections have abundant porous and permeable formations to allow migration.

The demarcation of the updip line of gas flushing is still tenable, despite migration across the sub Cretaceous unconformity from the subcropping formations, because of the differential entrapment of oil and gas. The gas in the subcropping formations will be trapped in deeper reservoirs, while the oil spills over to higher reservoirs, or escapes across the unconformity into the basal Cretaceous rocks. The regional tilt of the Palaeozoic rocks during their emergence and erosion has to be considered, and also the faster migration of gas if it ever did reach the outcropping edge. If it did, it would be lost, and as we have seen increased hydrostatic pressure, due to burial and tilting of the regional dip, will cause the gas to pass into solution in the oil and the oil to spill over into higher traps.

The Petroleum Geologist should be aware of these different interpretations and alternatives, so that he might direct his attention to the right locality. It is not inconceivable that many oil and gas pools lie undiscovered in different parts of the world because attention was directed updip after salt water had been struck in the potential horizon, instead of downdip.

BELLSHILL LAKE AREA

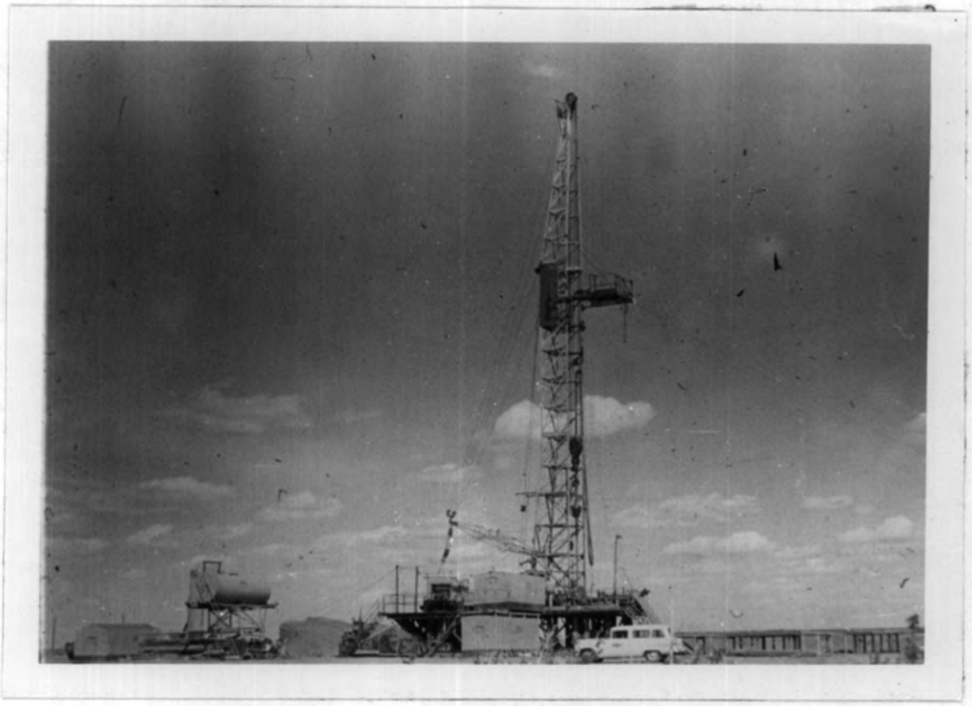
The Bellshill Lake oilfield is situated 140 miles north east of Calgary, 90 miles south east of Edmonton, 11 miles north of Alliance in and around Township 42 Range 12 West 4th Meridian (Figure 1).

The east central plains of Alberta have flat to gently rolling topography blanketed with glacial drift and elevated to about 2500' - 3000' above sea level. (Photo. 33)

The discovery well for this field was the Richfield McLennon No. 6-32 well in l.s.d. 6-32-41-12 W4M. The well was drilled to a total depth of 3220', topped the Palaeozoic sub-Cretaceous unconformity at 3185'. The producing formation, the Ellerslie Sandstone, a basal Cretaceous accumulation, was topped at 2950'. The formation was perforated between 2954'-2980', a gross pay of 37' and the well went on production with 118 barrels oil per day through a 29/64" choke.

This was not however the first well to be drilled in the field. In 1950 a well, the Albercan, Fina, Western Prairie Goose Lake No. 1 drilled in l.s.d. 13-28-41-12 W4M, drilled through about 36' of oil column in the Ellerslie Sandstone reservoir. No drill stem test was run nor was it recognised as hydrocarbon bearing from the electric logs. This is not as inexcusable as it may seem because the well is in a relatively low area and has one of the poorer sand developments.

Photo. 33.



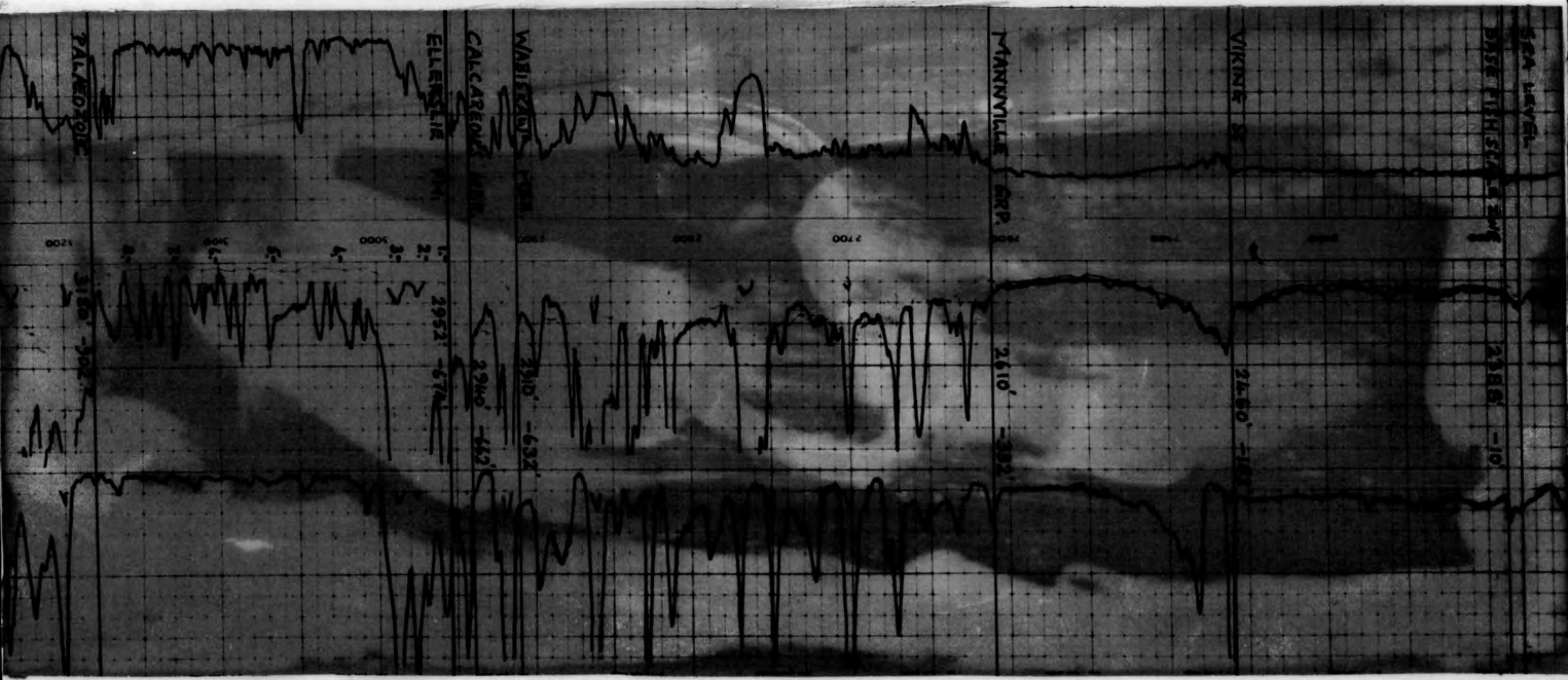
Drilling rig on location on the topographically flat Prairies.

Also the Western Canadian oil industry as we know it today was in its infancy and stratigraphic traps and permeability barriers, and all the features associated with these, were not understood and appreciated. However it is a sobering thought for the Petroleum Geologist that it was nearly seven years before the field was discovered and started to be delineated, and the lack of initial success didn't help the reputation of the Basal Cretaceous Sands as hydrocarbon reservoirs.

Subsurface investigation of a stratigraphic trap, is the most economic method under these conditions. The wells are relatively shallow and can be drilled quickly and cheaply. The principles learned here are applied to other areas of the basin. These include contouring all major horizons to look for embayments or troughs on the Palaeozoic erosional surface in which sand could accumulate and be winnowed. Also to look for structural elevation caused by differential compaction which causes a subdued reflection of the sand build-up on the shallow horizons. The geologist can only evaluate the evidence to see if a promising geological structure exists but only drilling will show if hydrocarbon is present. Favourable geological conditions can be interpreted and the sand build-up can be found but it may be water laden e.g. Bakke Amerada Schultz Lake No. 2-12 in l.s.d. 2-12-41-12 W4M. (Figure 20, Cross section 3)

Information for an initial study of suitable areas may be

Figure 10 . Typical Bellshill Lake Electric Log, eg. Hudsons Bay et al Bellshill Lake 14-27-41-12 W4M.



obtained from seismic surveys across the area to pick up the lows on the unconformity and the highs on the higher horizons if a stratigraphic build-up has occurred. The Petroleum Geologist has however to be aware of the pitfalls at seismic surveys on unconformity surfaces in an area like this because although the carbonate of the Mississippi and Devonian will generally provide a good reflector the weathered detrital zone on the erosion surface tends to give anomalous results due to masking. Therefore some lithological control has to be available before the seismic data can be trusted. Further, stratigraphic traps being lithogically graditional and intraformational seldom reflect distinctly on seismic records.

Bellshill Lake oilfield has a maximum reservoir thickness of 250'. There are secondary horizons in the section. Firstly, the Cameron Sand which is a thin porous sand just above the main sand but separated by a permeability barrier of argillaceous sand. It represents the winnowing of this earlier argillaceous sand by the transgressive sea. It is best seen immediately north of the Bellshill Lake oilfield area, the gas in these wells being produced from this zone in fairly substantial volumes. Secondly, the Viking Sandstone in the Colorado is a shaly sand overlying the field. Certain patches have been winnowed and cleaned by current action against the reflected high draping over the Basal Cretaceous sand and from some wells gas is produced e.g. Schultz Lake No. 4-15-41-12 W4M.

CANADIAN GEOGRAPHICAL CO-ORDINATES

TABLE 3

Ranges increase Northwards from 45th parallel line of Latitude.

Townships increase Westwards in Western Canada from the Prime Meridian (Line of Longitude) running through Ontario repeating themselves after each one. The Meridians are spaced every 4° of longitude.

A Township and Range consists of 36 square mile units called Sections.

A Section is subdivided into 16 legal subdivisions (lsd's) each of 40 acres in area.

31	32	33	34	35	36
30	29	28	27	26	25
19	20	21	22	23	24
18	17	16	15	14	13
7	8	9	10	11	12
6	5	4	3	2	1

Range 41

Township 12 W4M.

13	14	15	16
12	11	10	9
5	6	7	8
4	3	2	1

e.g. the type section used in this account for the Bellshill Lake Field is represented thus:- Hudson's Bay et al Bellshill Lake No. 14-27-41-12 W4M.

i.e. legal subdivision 14 in Section 27 of Range 41 Township 12 West 4th Meridian.

GEOLOGICAL SETTING

As indicated in the regional description, this field is situated in the Lower Cretaceous detrital fill on the sub-Cretaceous unconformity. Either meandering stream courses or advancing later marine waters winnowed, resorted and redistributed the sand to leave isolated hills upstanding rather like remnants of eroded river terraces or point bars. (Figure 11)

This alluvial channel, the southeast end of the Edmonton Channel, is 15 to 20 miles wide and so it is no surprise to find the conditions of formation of the Bellshill Lake oilfield repeated in adjacent areas in the oilfields of Hughendon, Choice, Thompson Lake, Alliance and Sneider Lake (Figure 10). Structurally high sandstone developments occur elsewhere but are water laden e.g. the Bakke-Amerada Schultz Lake 2-12 well in Lsd. 12-12-41-12 W4M, (Figure 21, Cross section 3).

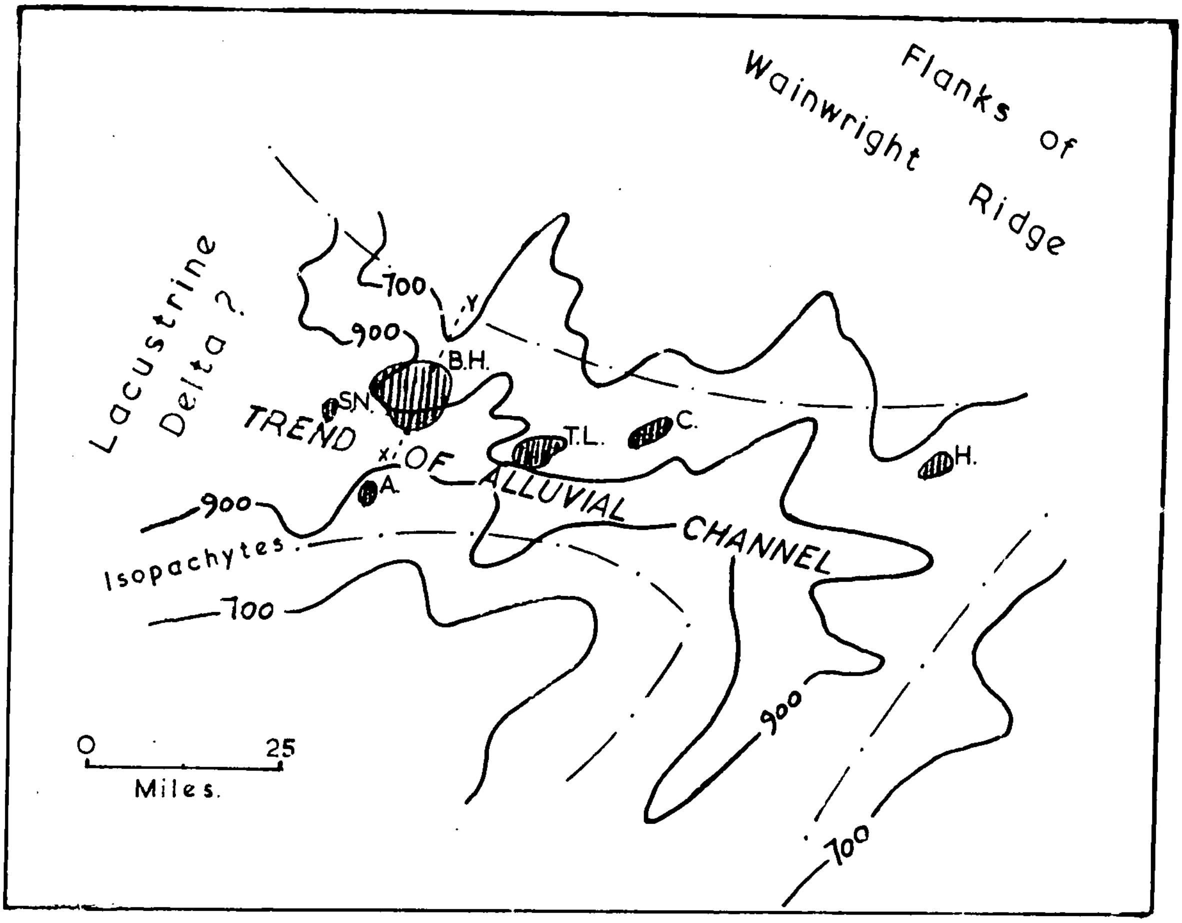
Further because of the relative structural high due to draping of the overlying formations, other sand zones have been winnowed in sand banks or bars, and these also provide porous and permeable horizons in some of which hydrocarbon is also found. A continued search will no doubt reveal other similar structures some of which will also contain hydrocarbon. But for the present more lucrative possibilities in other parts of the basin are being explored (Latus 1966).

The Palaeozoic contour map (Figure 13) in the immediate vicinity of the Bellshill Lake oilfield area, shows the gradual regional slope of the erosional surface to the southwest, off the flanks of the Wainwright Ridge. A spur projects across part of the oilfield more or less parallel to the regional slope and this may have been the site of a small tributary stream of the Ellerslie River system which flowed in an overall north-westerly direction; or it may be part of the meander belt of the river across the erosional surface. This feature is far from being as pronounced topographically as it appears at first impression from the contour map, as the spur is only about 30' high and the general slope of the erosional surface in the area is only about 20' per mile.

The contour map on top of the Ellerslie Sandstone, (Figure 14), shows a mound like structure with a relatively steep fall off to the north, northeast and east, and a more gradual slope southeastwest down the regional dip. This overall structure has a number of greater or smaller incisions running across it to produce a number of subsidiary mounds of variable area. In particular there is a low trend running northwest-southeast across the centre of the field with an overall relief difference of about 90'. In the northeast there is a similarly pronounced ridge on which the high wells of the field are situated.

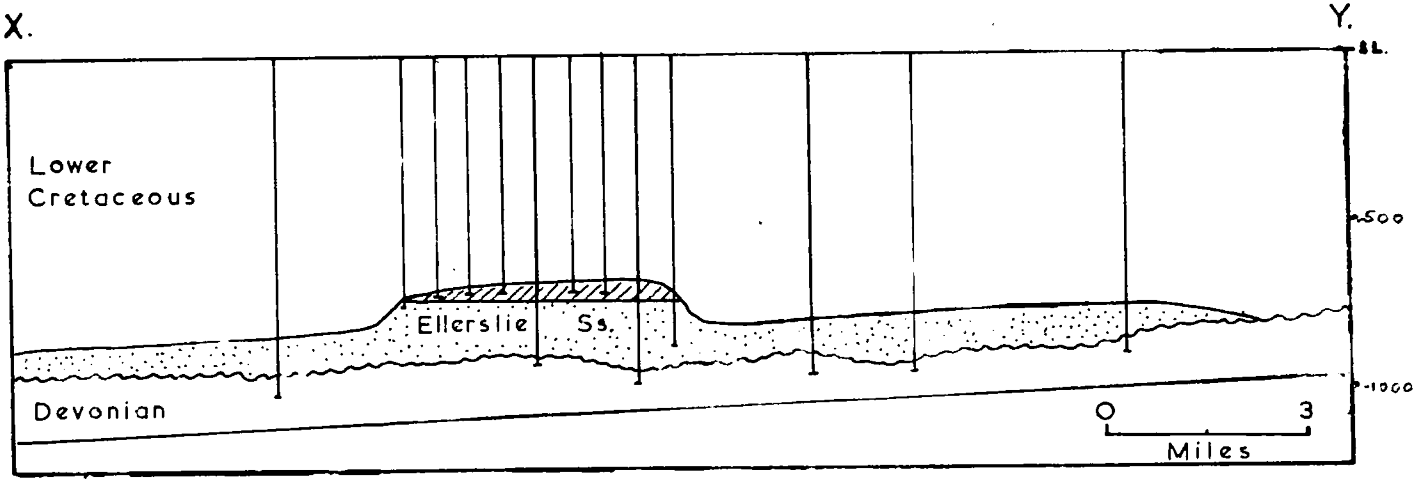
The isopachyte map of the Ellerslie Sandstone (Figure 15),

FIGURE 11.



Sketch diagram to show the trend of part of the Ellerslie River system and the distribution of the oilfields already found in the alluvial sand. Oilfields — B.H.=Bellshill Lake, C.=Choice, H.=Hughendon, S.L.=Sneider Lake, T.L.=Thompson Lake, A.=Alliance.

FIGURE 12.



Diagrammatic cross section (X-Y above) to show the flat topped terrace like erosional high on the alluvial plain of the Ellerslie Sandstone which lies unconformably on the Palaeozoic erosional surface.

shows that this ridge also has the best net pay oil zone in the field. Interpretation in anything but general terms of the isopachyte map would only be conjectural as, in keeping with normal oilfield development, field wells drilled after the field has been more or less delineated are drilled to a prognosticated "coring point". For this field the coring point is usually the Wabiskaw or Calcareous Members. The hole is then cored for a predetermined amount, usually about 30' (the core barrel being equal in length to one piece of drill pipe), to total depth, so that the water zone is not penetrated.

However, the mounds on the contour map are not coincident with the areas of equal net pay on the isopachyte map, with the exception of the northeast ridge and the southeast area of the field. This may be due to the lack of complete data, or as often happens with arenaceous stratigraphic traps, structure does not always correspond with the porous and permeable horizons. A comparison shows that a number of structurally high wells are rather poor in net pay. This can be due to the presence of argillaceous material forming an occluding matrix or pressure solution welding the grains together, sealing the intergranular voids, reducing the permeability and forcing the contained fluids to migrate to areas of pressure relief. (Waldschmidt 1941, Taylor 1950, Griffiths 1956).

The mounds forming the structural relief on the Ellerslie Formation, and the rapid fall off north, northeast and east, are likely to be due to facies changes from arenaceous areas, in the main river valley, to argillaceous areas, on the flanks of the alluvial plain and in local back waters. The argillaceous sediments are compressed by the overlying succession and differentially compacted. This leaves the more arenaceous areas structurally higher than contemporaneously deposited argillaceous rocks.

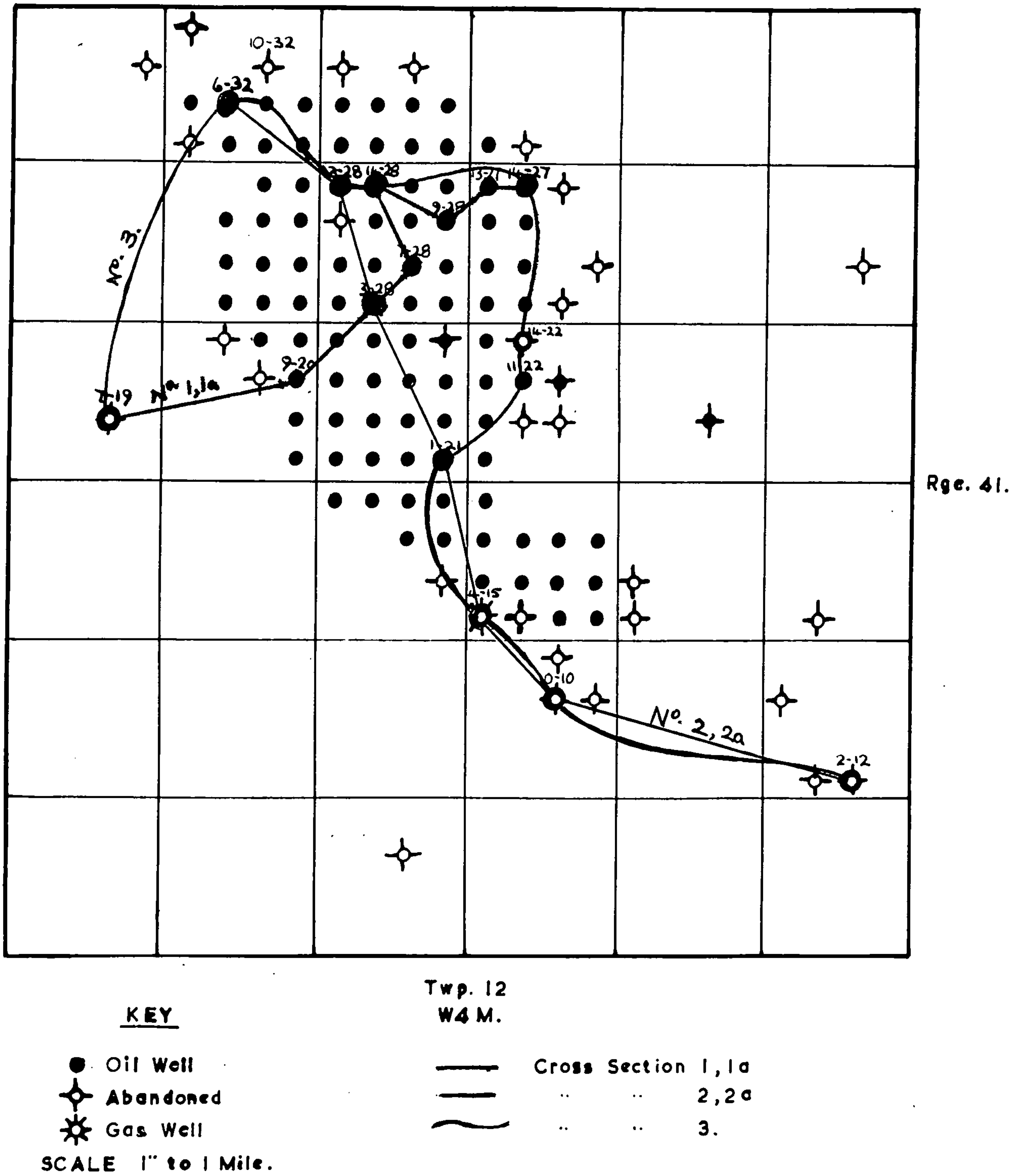
These structural highs on the Ellerslie Formation, not only in the Bellshill Lake area, but in other areas throughout the province, have caused the reworking and winnowing of sediments above them and produced banks or bars of porous and permeable sand horizons in which hydrocarbons have accumulated. Immediately above the main Ellerslie Sandstone, separated by an interbedded shale, are a series of thin sands of poor continuity but as much as 58' thick. This is called the Cameron Zone, a local name in the Bellshill Lake area, for the spasmodic zone above the true Ellerslie Sandstone and from which some natural gas is produced, e.g. the few wells immediately north of the Bellshill Lake field.

At a higher elevation over the field some of the mixed argillaceous-arenaceous sediments of the Viking Zone (Figure 3), have been reworked and resorted in the high areas and also produce natural gas, e.g. the Hudson's Bay Schultz Lake well in Lsd. 4-15-41-12 W4M.

The amount of apparent closure on the main sand is over 100' to the east. This is reduced to 70' on the Calcareous Member

LOCATION MAP OF CROSS SECTIONS ILLUSTRATED IN THE TEXT

FIGURE 16.



horizon, to 30' on the Base of the Fish Scales Zone, and to 15' on the Lea Park horizon in the Upper Cretaceous. However the general configuration of the Bellshill Lake sand body including the northwest-southeast low trend, is still reflected in the drape of this horizon almost 2000' above. A shallow core hole programme to pick up the structure on this shallow horizon which reflects the structure of the Ellerslie Formation might usefully be undertaken.

Cross sections 1 and 1a. (Figures 17 and 18 respectively) represent the structural elevation of the marker horizons in a southwest-northeast direction across the Bellshill Lake oilfield. Cross section 1, shows the thickness of the Ellerslie Formation, the average thickness of the sandstone in the adjacent area, the thickness of the sand in the field and its irregular knob-like surface, and the amount of drape of the overlying horizons as it is at the present day, incorporating differential compaction and regional tilt with sea level as datum. Cross section 1a, with the top of the Calcareous Member taken as datum, since this horizon marks a marine transgression, has all the subsequent drape and regional tilt removed, and shows the structure of the Ellerslie Formation very soon after its deposition and early in the degree of compaction.

Cross sections 2 and 2a, (Figures 19 and 20 respectively) run at right angles to the above, i.e. northwest-southeast, and are more or less parallel to the strike of the field. They represent the same horizons, and datum is the same as before in each case. Similar features are to be noted, as already described above. Two important additional features are, however shown, and these are, firstly, the influence of the topography of the Palaeozoic erosional surface in limiting the thickness of the sandstone accumulation, cf. the Richfield Schultz Lake No. 10-10 well; and secondly the increase in thickness of the Ellerslie Sandstone as a new development builds up in the southeast, the Bakke-Amerada Schultz Lake 2-12 well in Lsd. 2-12-41-12 W4M.

Cross section 3(cf. Figure 12), is compiled from all the electric-logs in the Bellshill Lake oilfield area which penetrated the complete Ellerslie Sandstone and went into the Palaeozoic. The tops of the marker horizons are prominent but the structure is not plainly demonstrated because of the meandering course of the cross section around the field. Notice is drawn to the blocky, if somewhat serrated, nature of the self-potential curve of the Ellerslie Formation, indicating the porous and permeable nature of the sandstone. Also, the proximity of the resistivity curve to the base line, indicates the water saturated zone, and the way this curve kicks out to the right denotes the hydrocarbon laden zone at the top. The facies changes of the succession can be clearly seen.

DEPOSITIONAL ENVIRONMENT

It is most important, if the Petroleum Geologist is to prognosticate a new area for investigation or a suitable area for further investigation, that every piece of data should be recorded and collated and the information should be reviewed periodically in the light of new developments and techniques. Descriptions of drill cuttings, cores and electric logs are fundamental, yet often pieces of information they contain are overlooked or ignored, perhaps because of a difficulty in finding an acceptable explanation. It must be stressed at this point that observations of features which in the first instance are not readily explainable should be recorded particularly in core or other rock descriptions. Very often only the core report remains accessible for reference at a future time, the actual core having been broken up virtually beyond recognition, misplaced in its boxes, shipped to the other side of the country or thrown away. It cannot be too strongly emphasised that indiscriminate sampling of cores destroys a record that may be vital and certainly cannot be replaced.

It is recommended that the Petroleum Geologist should photograph all core from exploratory wells and selected sections from development wells (Photo. 31). This procedure is not only helpful in the elucidation of core descriptions and problems arising from them but is a guarantee that if damage or loss occurs to the core there is a permanent visual record. If the core is cleaned of drilling mud and photographed wet, it is remarkable how faithfully lithological variations and sedimentary structures are recorded in a 4' - 5' section. For more detail a close up of 6" - 12" of core can be helpful (Photos. 23 to 31).

Further the geologist should record the amplitude of the ripples and the angle of dip shown by the cross bedding. The result may be a definite clue to the depositional environment. Other features such as graded bedding, churning by molluscs and worms, disruptions and contortions caused by slumping and strong currents, and tubes formed by roots may seem of academic interest only to the well site geologist principally interested in winning oil or natural gas but they may be significant features in appreciating the geological conditions of deposition and lead to successful exploration. The geological interpretation of a core is merely a first step in the reconstruction of local and regional depositional history.

It is only during the last decade, in the author's experience, that government Conservation Boards have started preserving, or compelling the oil companies under their jurisdiction to preserve, representative samples, usually in the form of a complete vertical sliver, of the otherwise very bulky core.

The recognition of depositional environment is of primary importance for it will give significant information about the rocks being studied. This is especially true in the study of sand bodies of the Lower Mannville type. It is important to recognise it as an alluvial sand (Conybeare 1964) to distinguish it from other possible types of sand accumulations say a marine beach bar sand (Sabins 1963). From this the configuration of the depositional trend can be established. The interpretation of its mode of formation and structural influence can increase the chances of successfully selecting a site and drilling to a potential hydrocarbon reservoir.

Alluvial sands can be good reservoirs but they are commonly very elusive stratigraphic traps. This is inherent in the nature of the sands because their trends are difficult to predict and their porosity and permeability variable.

The identification of the Lower Mannville Ellerslie Sandstone as an alluvial sand filling the south east Edmonton Channel is based on a number of observable criteria.

Firstly, fossils render identification relatively simple if it is obvious they are not derived. Fossils found in core are more acceptable than those amongst drill cuttings as fragments from higher horizons are commonly dislodged by the collision of the rotating drill pipe on the sides of the hole and these fossils may be out of place. No fauna has been found in the Ellerslie Sandstone in the Bellshill Lake area. But there is little doubt of the alluvial origin of the formation due to the presence of plant fragments and rootlets in place (Photo. 27, 28), mostly preserved as carbonaceous markings, and also coal stringers (Figure 22).

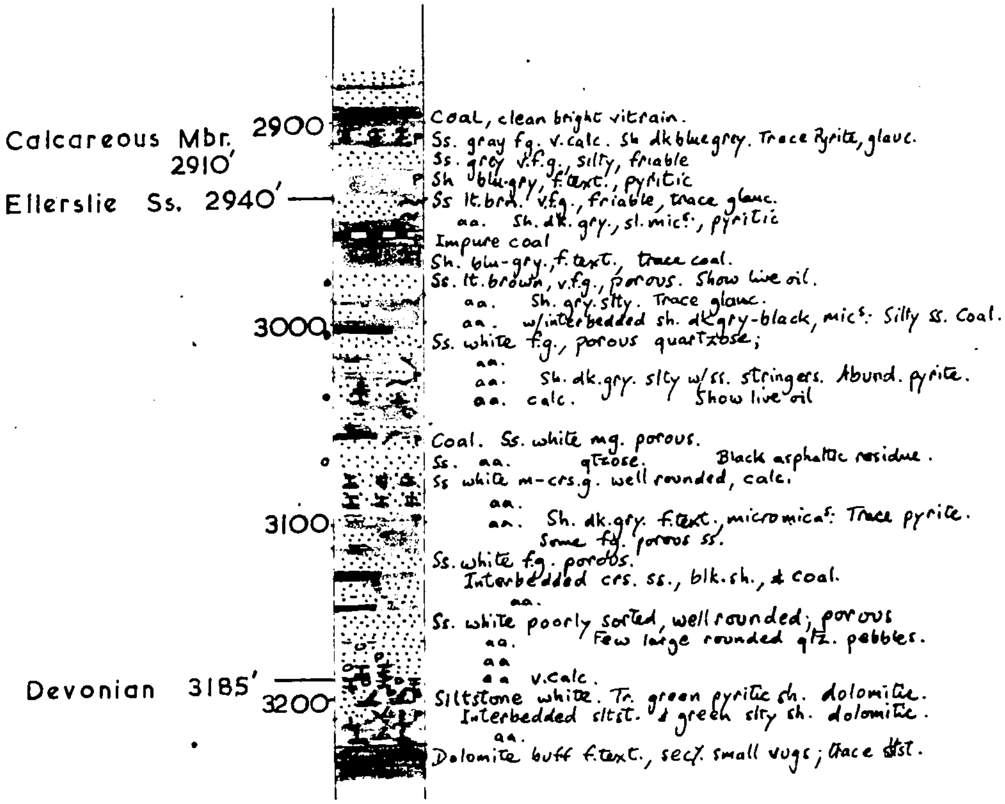
The presence of marine fossils and glauconite in the overlying Wabiskaw and Calcareous Members indicates that subsidence of the area allowed a marine transgression across the alluvial plain.

Further evidence can be obtained from drill cuttings and core. The basal deposits of the Lower Mannville consist of poorly sorted material, large rounded quartz and chert pebbles and grains, together with some angular detrital chert, siderite pebbles and red and green argillaceous fragments all set in silty matrix. This is typically the type of material accumulating on an unconformable erosional surface and inundated by a river system. The grain size grades to finer above, a further typical feature of alluvial sands although this is shared by other distinct sedimentary formations.

Sedimentary structures can be examined in cores and their correct interpretation is essential in determining depositional environment. The Petroleum Geologist must attempt to place the formations with which he is dealing in their correct palaeogeographical perspective. Cross bedding is seen representing the foreset of migrating ripples produced by current transport. The angle of dip is usually around 20°-30° although the precise angle can be misleading due to deviation of the hole from the vertical during drilling, as commonly happens when too much weight is allowed on the drilling bit.

FIGURE 22.

Lithologic Log of lower part
Hudson's Bay et al Bellshill Lake No. 14-27-41-12W4.



Scale 1" to 1000' to correspond to electric log scale.

This can easily be checked however when the hole is completed, as a dipmeter survey is compulsorarily run to check the exact location of the bottom of the hole. These cross beds are characteristic of point bar river deposits formed on an upper alluvial plain above a delta. The ripples or individual cross beds are seen to range in vertical thickness from a few inches to two feet (Photos) and smaller cross bedding less than an inch in thickness has developed in the finer sediments in the upper part of the point bar deposit. (cf. feathering on S.P. curve of e-log). Clay layers formed in backswamps, lakes, and cut off portions of the river are associated with alluvial sands and silts. Abundant carbonaceous material and thin layers of coal are shown on the stratigraphic lithological log and characterise alluvial deposits.

Further confirmation, that the Bellshill Lake Lower Mannville sands are alluvial, can be obtained from the characteristic shape of the self-potential curve of the electric log. The ideal curve for an alluvial sedimentary gradation is bell shaped, where there is a grain gradation from coarse to fine upwards. The S.P. curve, in general, represents the permeability of the formation, (if the formation water is more saline than the drilling fluid), being greatest the further the curve is from the central base line. The type electric log presented for the Bellshill Lake field is the Hudson's Bay et al Bellshill Lake 14-27-41-12 W4M, which shows a considerably more blocky or rectangular overall appearance (Figure 10), but it does still show the shoulder representing the fine grained sediment at the top. The feathered edge represents very thin lenses of less permeable, probably finer material, and may be interpreted as changes in the meander belt as the river changed its course gradually across the alluvial plain.

Having established that the Lower Mannville in the Bellshill Lake area is an alluvial accumulation from the fossil evidence, cross bedding, grain size gradation and the electric log character, it is now necessary to establish the trend of the deposit to delineate an area for closer investigation to locate similar stratigraphic traps. The depositional trend in the Bellshill Lake area is shown by isopachs of the Ellerslie Formation (Figure 15) to be broadly linear. This trend has established the area of investigation and as shown (Figure 11), a number of oil fields or structures, have already been located and developed. Further, more precise, locations may be determined by a closer look at the structure, the lithology, and the hydrodynamics of the deposit.

In the case of the Bellshill Lake field, the oil is trapped in flat topped hills of reworked alluvial sand (Figure 12) capped by siltstones and mudstones, and the overlying sediments for over 2000' are draped over these residual highs, due to differential compaction. It is suggested that the subdued highs on, for example, the Lea Park horizon in the Upper Cretaceous at a depth of some 1200', could be located very quickly and cheaply, by using a portable drilling rig and a 2" drill line to core to and establish the structure of this key marker horizon. Contour maps for this horizon from the data will indicate the buried highs on the Lower Mannville. (As stated earlier, this represents suitable geological conditions only, and does not assure hydrocarbon accumulations to be present. The Bakke-Amerada Schultz Lake well in Lsd. 2-12-41-12 W4M has an excellent, structurally high sandstone development, but is water laden).

Bernard and Major's results (1963) in their account of the recent meander belt deposits of the Brazos River near Richmond, Texas, show a striking similarity with the Lower Mannville Ellerslie Formation and tend to confirm the interpretation of its alluvial origin. Typically these are point bar deposits of an alluvial meandering stream and form the principal meander belt deposits. They consist of a sequence of fine sand and silt grading downwards into coarse sand and gravel and further the more turbulent sedimentary structures are found towards the base.

A typical section can be divided into four generalised zones from the top downwards, each characterised by a particular class of sedimentary structure.

(i) Small ripple or small scale crossbedding.
(ii) Horizontal lamination.
(iii) Giant ripple or medium scale crossbedding.
(iv) Poor bedding.

This is an offlap sequence deposited on the convex (depositional) side of the meander curve as the stream meandered laterally towards the concave (erosional) bank. The average thickness of this section is 55' which equals the average maximum depth of the river during flood stages. The Ellerslie Formation is interpreted as a repeated sequence or modified complex of this same type and the bell-shape of the self potential curve of the electric logs is used as evidence (Figure 10).

As the stream meanders within its belt it produces a suite of deposits consisting of sediments characteristic of point bars, natural levees and fills of abandoned channels and oxbow lakes. The lithologic logs and core descriptions are interpreted to represent these features.

Abandoned channel fills consist principally of laminated and bedded clay and silt. They are tortuous and arcuate in ground plan, a few hundred feet wide and their cross sections are roughly U-shaped. These deposits usually range from a few feet to approximately 40' thick and usually occupy positions within the upper two-thirds of the compounded point bar section. This type of finer and more argillaceous type of sedimentation could account for the differences in thickness of the gross pay sections and permeability barriers affecting the reservoir characters in the Bellshill Lake field and is a common occurrence in other oil fields in the basin in Ellerslie

Formation reservoirs. Differential compaction would accentuate the structural configuration of the more arenaceous parts.

Flood basins within the alluvial plain are adjacent to the meander belts and are topographically lower, approximately 5 feet, than the uppermost point bar and natural levee sediments. The flood basin deposits are laminated and poorly stratified sandy clay and silt containing numerous soil zones and calcareous and ferruginous nodules. This is a further observation which essentially agrees with the lithological and petrographical observations of the Ellerslie Formation.

The deposition of this sequence, during the Late Recent standing sea-level stage, has taken about 3500-5000 years. The river has developed and abandoned several meander belts within its alluvial plain, which is approximately 7 miles wide at this point, and most belt trends are approximately at right angles to the regional depositional strike. The Ellerslie Formation has a considerably longer period of time for accumulation but the lack of a proportionate increase in thickness of the deposit is no difficulty in this analogy. Subsidence was extremely slow so that very considerable reworking, resorting and redistribution of the material of the Ellerslie River alluvial plain is to be expected. This has resulted in the build up of a composite section as stated earlier, and this feature is reflected in the angular blocky outline of the self potential curve on the electric logs, which terminate with the bell shaped slope at the top as the final alluvial phase ends due to subsidence and the marine incursion.

Control is essential in stratigraphic interpretation and often it is lacking or insufficient, frequently due to poorly recorded information in the original core and drill cutting descriptions. This is the sole responsibility of the Petroleum Geologist at the well site. It is necessary to continually review and re-evaluate the data in an area of stratigraphic traps, as the one in this thesis, as new information becomes available, perhaps from a new wildcat or stepout, and to produce new ideas on which to base economic exploration.

ENGINEERING AND FIELD DATA

Many wells in the Bellshill Lake oilfield have been cored for at least a part of the pay section (it is preferred not to core or drill into the water laden zone of the formation) and there is thus a large amount of data available on which to base a volumetric estimate of original oil in place and other reservoir characteristics.

In making use of this data two principle problems arise:-

1. the relation of a proper permeability for porosity cut off and
2. the determination of the interstitial water content of the reservoir.

The two problems are inter-related because the choice of a cut off will depend on the oil producing potential of each permeability or porosity group and this in turn will be directly related to the interstitial water saturation of the group. The determination of the interstitial water content of the reservoir is complicated by the existence of a transition zone of water saturation which extends above the free water level, through a substantial portion of the oil column in many instances. A further complication may be recognised when contamination of the core has occurred by other than formation fluids (see later). The interstitial water saturation will therefore depend on both elevation and rock properties, and the low gravity contrast between the formation water and the reservoir oil shown by analysis of capillary pressure data is an additional factor.

The field contains 91 producing wells on a 40 acre spacing pattern which encompass a total proven area of some 3640 acres. Production is obtained from essentially a stratigraphic trap at the top of the Ellerslie Sandstone at a depth of approximately 3000'. After drilling is completed Schlumberger E.S. Induction and Microcaliper logs are run from the surface to total depth. From these stratigraphic correlations can be made by a comparison of similar kicks on the curves. Zones of porosity are checked to make sure that everthing of potential exonomic significance has been tested. The relationship and spacing of the curves on the various logs can be used individually or in combination to evaluate formation characteristics and provide calculated reservoir data.

Surface casing is set to 450' and 7" or $5\frac{1}{2}$" production casing set to total depth. Radioactivity logs (gamma ray/neutron) are run to pick up the casing connections to correlate before perforations are made through the casing into the formation, preferably about 20' above the water line.

The stratigraphic trap is a pronounced structural feature overlying and essentially continuous with the underlying and wholly water bearing main sand development. The study of electric logs and core analyses indicates the oil-water contact is generally at 720' subsea in the northern part of the field but varies from -710' to -715' locally due to small areas of lower permeability the gas-oil contact lies at 667' subsea giving a maximum gross oil column of 53'. Small isolated gas caps occur locally at the high points of the structure up to a maximum of 25' thick.

In the southern portion of the field the elevation of the water-oil contact varies between 710' and 705' subsea. The gas-oil contact in the southern sector has not been definitely established but the available evidence indicates its probable elevation to be at 660' subsea. The northern and southern sectors of the field are referred to as the Main Pool and the Southern Pool respectively.

The oil-water contact in both pools is approximately 5 feet above the theoretical free water level i.e. it corresponds to a height at which due to capilliary forces, the higher permeability samples exhibit essentially 100% water saturation. From this it may be inferred that the free water level in the Main Pool is 725' subsea and in the South Pool at 715' subsea. This relatively extensive transition zone is responsible for the increasing production of salt water with the oil, but after settling and separation in the stock tanks, the salt water produced is injected into the base of the producing sand. A number of marginal wells have been converted for this purpose, as can be seen from the borehole symbols on the maps labelled S.W.D. = salt water disposal well.

The reservoir consists of fine grained, well to fairly well sorted, moderately friable sand, with erratically occurring shale bands and lenses. (This lithology contrasts with the lower, water bearing, zones of the formation, which varies from fine to coarse grain size and is generally well sorted with occasional less permeable layers). The thinner pay sections around the margins of the field exhibit a higher percentage of shale in the gross sand thickness, in keeping with a facies change, the reservoir sand being more poorly sorted with some argillaceous infilling of the matrix. Porosity varies from 9-33% and permeability varies from less than 1 millidarcy to as high as 10 darcies. The vertical permeability is also variable being as high as 90% of the horizontal permeability. The lower values of porosity and permeability are generally characteristic of the thinner pay sand sections of the field particularly approaching the margin and this is consistent with the geological interpretation. The average field well has a net pay thickness of 32', a porosity of 27% and permeability in the order of one darcy.

Bellshill Lake Oilfield - some typical reservoir data:-

TABLE 4

Well No.	Footage analysed	Permeability (md.)	Porosity %
4.27	16.6	6,657	29.9
5.27	17.0	4,499	28.2
11.21	8.0	410	17.8
13.21	8.7	568	24.2
14.21	8.3	639	24.9
2.28	22.5	455	22.1

(after Miller)

The existence of an original gas cap indicates that the reservoir pressure and temperature of 935 psig and 93°F. The solution gas-oil ratio by differential liberation of a sub-surface sample is 151 cubic feet per barrel. Sulphur is present in the produced oil up to 1.6%. The stock tank gravity of the oil is 27° API. The saturated reservoir oil has a viscosity of 9.25 centipoises at original reservoir conditions and the estimated viscosity of the formation water is 0.85 centipoises. The densities of the formation water and oil are respectively 1.06 and 0.85 grams per c.c.

The high oil-water viscosity ratio and the low gravity contrast indicated by the above data reveal the cause of the high rate of water production from the field. Simply, the oil is more strongly held in the formation than the water due to its viscosity; and the fairly large transition zone, mixed oil and water zone, is due to the closeness of the fluid densities. A large volume of mobile water is present in the formation which drives the oil out into the borehole but also tends to be produced with it.

Original oil in place is in the order of 1500 stock barrels per acre foot giving a total of approximately 150,000,000 barrels in place of the proved and developed area of the field. Estimated original recoverable reserves of 20-25 million barrels have been calculated of which 7,235,000 barrels had been produced to 1st July, 1965. The reservoir is subject to the very effective natural water drive originating in the extensive Ellerslie Formation aquifer and also possible some gas cap expansion although this latter is only present in a few wells.

Very great difficulty is found in obtaining reservoir data which are worthy of consideration due to contamination of the core before analysis was made. Comparisons were made by Miller of cores cut with oil-based drilling mud and those with ordinary water-based drilling mud and further those cores from holes which stopped drilling above the reservoir, changed mud to oil-based, then cored. It was found that there was a wide discrepancy between results and that those cores which were exposed to any form of water contamination showed water saturation values considerably higher than those in which contamination had not occurred. It is of interest to note that less than 0.4 gallons of water is required to raise the saturation of a 20' core having 30% porosity and good vertical permeability from 5 to 20% pore volume. This is a further instance in which a Petroleum Geologist conversant with the methods of study and requirements of the Petroleum or Reservoir Engineer can make decisions of significance for everyone's advantage.

Production from the field is limited by good conservation practise to a maximum permissive rate (M.P.R.) of 80 barrels of oil per day per well although most wells are capable of considerably higher production (see net pay isopach Figure 15). But because of the economic situation i.e. saturated markets, this figure is reduced to between 20-30 B.O.P.D. per well. The oil is transported along the Gibson pipeline to the Hardesty pump station of the Inter-Provincial Pipeline Co. and thence through Regina, the U.S.A., to oil refineries in Sarnia and Eastern Canada.

MECHANICAL ANALYSES

Mechanical analysis is used to determine the grain size distribution and other parameters of a sedimentary rock. The diamond core rock samples of the Ellerslie Sandstone from the Hudson's Bay et al 14-27 well, (Figure 11) were disaggregated using an iron pestle and mortar, taking care not to pulverise the grains to powder. The friability of most of the specimens considerably aided in this operation. In order to ensure that the grains are completely separated they should be examined with a hand lens or a binocular microscope.

The grains from each specimen were then seived, dry, on an 'Endrock Vibrator' mechanical shaker for twenty minutes each, using British Standards seives 410;1962, of the following sizes:-

TABLE 5

Mesh.	μ	Inches.
30	500	0.0197
60	250	0.0098
72	210	0.0083
100	150	0.0059
120	125	0.0049
150	105	0.0041
170	90	0.0035
200	75	0.0030

The separated fraction from each seive was individually weighed and the totals added together to compare the total seived weights with the initial bulk weights of the disaggregated samples. No significant loss was measured.

An Elliott 803B computer using Algol code was fed these weights and programmed to calculate the weight percentages and group the data in weight percentages according to Wentworth's Scale.

TABLE 6

Mechanical Analysis Weight Percentages, Ellerslie Ss.
from Hudson's Bay et al Bellshill Lake 14-27-41-12 W4M.

Spec. No.	500µ >30	250µ 60	210µ 72	150µ 100	125µ 120	105µ 150	90µ 170	75µ 200	<200	B.S. 140;62 Mesh
1.	2.31	3.18	29.25	42.31	7.78	8.89	2.19	2.01	2.07	
2.	4.44	4.13	30.10	44.28	4.90	5.52	1.79	2.39	2.45	
3.	4.28	20.65	22.24	39.13	5.79	3.51	1.07	0.99	2.36	
4.	5.05	50.51	26.40	5.85	2.62	2.24	3.49	2.35	1.48	
5.	27.41	54.99	8.04	1.77	2.23	3.05	0.35	0.33	1.83	
6.	2.70	6.36	30.51	36.58	6.84	8.53	3.37	1.98	3.13	
7.	6.63	57.40	28.68	3.40	1.21	1.01	0.69	0.32	0.65	
8.	13.92	56.25	22.63	2.86	1.07	1.07	0.43	0.43	1.36	

coarse	medium	fine	very fine	Wentworth
		79.34	15.17	
		79.27	12.16	
		67.15	7.92	
		34.87	9.57	
		12.04	5.56	
		73.93	17.01	
		33.29	2.67	
		26.55	3.28	
Average coarse sand =8.34%	Average medium sand =31.68%	Average fine sand =50.80%	Average very fine sand =9.16%	TOTAL 99.98%

The results are presented in the form of histograms (Figure 20) to show the grain size relationships. Attention is drawn to the correlation of this data with the position of the self-potential curve on the electric log, which amongst other things, represents changes in grain size and permeability at different depths through the sand body.

Specimens 1 and 2 are taken from a position at which a fine grained fraction is dominant in the Ellerslie Sandstone section and the self-potential curves are not far from the base line (i.e. the shale line), indicating a poorly sorted sandstone.

Specimen 3 shows a moderate decrease of fine grained material and a corresponding increase of medium grained particles. The self-potential curve is starting to kick outwards indicating a cleaner lense with increased porosity and permeability.

Specimens 4 and 5 show a predominance of medium grain sized particles. In the latter there is a large increase in the proportion of coarse grain particles which in this section are second in abundance after medium grain sized particles. This is also reflected in the position of the self-potential curve on the electric log. It is noteworthy that the self-potential curve of the electric log shows the increase in coarseness and the corresponding increase in porosity and permeability. This rectangular, or 'bell' shape of the self-potential curve is characteristic of alluvial sands which fine upwards (Conybeare 1964). The self-potential curve of the

Ellerslie Sandstone section is more rectangular in overall shape as it is a repetitive sequence of alluvial sands which have accumulated successively on top of each other, until rounding off in the typical 'bell' shape on the final cycle. In a comparison of the somewhat serrated blocky self-potential curve of the Ellerslie Sandstone in the type well, the Hudson's Bay et al Bellshill Lake 14-27-41-12 W4M, with the lithologic log of this well, it is seen that the section consists essentially of alternations of coarse through to fine grained lenses, together with occassional intercalated shales or coal stringers. These sequences represent incomplete 'bells' stacked one on top of another reflecting current direction change. (cf. the shape of the self-potential curves on the electric logs across the Bellshill Lake oilfield shown on Figure 21, Cross section 3)

Specimen 6 represents one of these fine grained sandstone intercalations towards the top of a 'bell' on the S.P. curve of the electric log and this character is very clearly demonstrated on the histogram.

In specimens 7 and 8 the medium grained fraction is dominant. (These last three specimens are within the producing zone of this well, as indicated by the kick of the resistivity curve to the far right. The oil-water contact is at 2996' which is -718' subsea, taken where the resistivity curve returns to the base line indicating a water saturated zone. The average oil-water contact for the northern or Main Pool is -720' (cf. Figure 15). This gives 56' of gross pay sand for this well).

The computer was also programmed to draw cumulative curves (Figure 24) for the weight percentage data and from these to calculate the median grain size, the coefficient of sorting, the skewness, and the kurtosis for these representative samples of the Ellerslie Sandstone from the type well.

The cumulative curves plotted by the computer have grain size on a semi-logarithmic scale, the abscissa, and the cumulative weight percentage on an arithmetic scale, the ordinate.

The cumulative curves are basically similar and correspond to the two grain size types shown on the histograms, viz. specimens 1, 2, 3 and 6, are dominantly fine grained, while specimens 4, 5, 7 and 8 are dominantly medium grained.

The steepness of the curve indicates the degree of sorting irrespective of grain size. The steepest curve, indicating the very best sorting, is shown by aeolian sands and delta foresets. These curves (Figure 21) are somewhat less steep and are in keeping with an alluvial environment of deposition, reworking, winnowing and resorting being caused by migrating channels.

Parameters which were calculated from the curves are as follows:-

1. the median grain size (Md.) is read directly from the graph, vertically down from the intersection of the 50% line and the curve, onto the grain size scale, (the abscissa).

2. the sorting coefficient (So.) is calculated according to the formula:-

$$So = \sqrt{\frac{Q_3}{Q_1}}$$

where Q_3 and Q_1 are the 25% and 75% quartiles respectively, and can be read directly from the graphs in the same manner as the median grain size. The sorting coefficient measures the sorting or spread of the curve. A perfectly sorted sediment has a sorting coefficient of 1.0, less than 2.0 indicates good sorting, while over 3.5 is poorly sorted.

3. the skewness (Sk.) parameter expresses whether coarse admixtures exceed fine admixtures. It is calculated by dividing the product of the quartiles by the square of the medium size, thus:-

$$Sk = \frac{Q_1 \, Q_3}{Md^2}$$

Perfect symmetry has a value of one, all other values being positive if above one, and negative if below one. With positive skewness coarse material exceeds fine, and with negative skewness fine material exceeds coarse.

4. the kurtosis (K.) is a measure of the distribution of the grains about the median diameter and represents the selective

action of the geological agent. It is calculated on the following formula:-

$$K = \frac{(Q_3 - Q_1)}{2(P_{10} - P_{90})}$$

P_{10} and P_{90} represent the 10 and 90 percentiles read directly from the cumulative curves. A value of 0.3 indicates strong concentration (peakedness), a value below 0.2 indicates greater dispersion.

The results are presented in tabular form below:-

TABLE 7

Mechanical Analysis Results

Specimen Number	Median Grain Size (Md.)	Coefficient of Sorting (So.)	Skewness (Sk.)	Kurtosis (K.)
1.	186.01μ	1.2082	0.98078	0.26869
2.	192.67μ	1.1944	0.97562	0.25909
3.	204.94μ	1.2295	0.98333	0.15145
4.	269.84μ	1.3151	1.14830	0.23699
5.	376.10μ	1.0269	1.56152	0.37040
6.	190.78μ	1.2270	0.95053	0.27304
7.	296.18μ	1.3087	1.06790	0.31260
8.	320.52μ	1.3457	1.02260	0.36508

The results confirm that the Ellerslie Sandstone, as described in hand specimens, core samples, and from thin sections, is essentially a fine to medium grained rock. The smallest of the median grain size values, Specimen 1, is well up in the fine grained scale of Wentworth, and the coarsest grained sample, Specimen 5, is high in the medium grained size range of Wentworth. The average median grain size for these results is 254.63µ with a standard deviation of 65.89µ.

The mechanical analysis weight percentages indicate that the average values for the samples in this well are:- 8.34% coarse sized sand grains, 31.68% medium sized sand grains, 50.80% fine sized sand grains and 9.16% very fine sand and silt grains.

All specimens have coefficients of sorting below two and are therefore classified as well sorted. The best sorting is shown by Specimen 5 with a value of 1.0269, which is extremely well sorted, and it is interesting to note that this specimen has the greatest median grain size.

The skewness parameter values deviate from perfect symmetry, with a value of one, the figures greater than one are positive, and indicate coarse material greater than fine, and negative values, those less than one, which indicates fine material is in excess of coarse material. These values again confirm the histograms. Specimens 1, 2, 3 and 6 having negative values, are seen to have finer material in excess of coarse, while Specimens 4, 5, 7 and 8 have positive values with coarse grains exceeding fine material.

The values for kurtosis, where >0.3 indicates strong concentration, and <0.2 greater dispersion, indicate that Specimens 5, 7 and 8 show strong concentration (peakedness), while Specimen 3 shows the greatest dispersion. This can again be seen to be pictorially true on the histograms.

The sorting coefficient and the skewness are of particular interest since they provide information for the interpretation of the depositional environment.

HEAVY MINERAL ANALYSIS

Heavy mineral samples were collected from diamond core specimens from the Hudson's Bay et al 14-27 well in Lsd. 14-27-41-12 W4M, in the Bellshill Lake oilfield. The core specimens are numbered one to eight, and were collected from the following elevations:-

2953' (-675'), 2968' (-690'), 2986' (-708'), 3023' (-745'),
3066' (-788'), 3102' (-824'), 3128' (-850'), 3157' (-879'),

respectively, and their positions are represented on the electric log of the Hudson's Bay et al 14-27 well, which is taken as typical for the field (Figure 10).

Careful disaggregation of the rock samples is necessary. This is done by placing one or two small chips, about one cubic inch in size, into a mortar and gently tapping them with the pestle; grinding should be avoided as this causes the grains to fracture. The process is repeated until sufficient material is obtained to perform the separation. To ensure that the mineral grains are completely disaggregated a part of the sample should be examined under a binocular microscope or with a hand lens.

The conventional two funnel apparatus, using bromoform (tetrabromethane $CHBr_3$) S.G. 2.90 @ $20^{\circ}C$, was used to separate the heavy accessory minerals from the lighter material. The heavy mineral assemblage of the Ellerslie Sandstone forms a very small percentage of the total weight of the rock, varying from 0.01% to 0.1%. The heavy minerals were mounted in clove oil, a very suitable temporary mountant, which facilitates easy manipulation for refractive index tests, whilst also retaining the grains in a semi-permanent mount on the microscope slide when the oil is allowed to dry on a hot plate. The heavy mineral grains were examined under a binocular microscope using reflected light which shows up the colour shades more clearly than transmitted light. The grains can be spread on a black square plate, on which is drawn a white net of 400 squares, the side of each square being two millimetres in length. Two sides of this net are numbered to facilitate the counting of the grains, or traverses can be made across each slide using a mechanical stage and point counter. It is shown by other workers (Dryden 1946, Robson 1956, etc.) that satisfactory results are still obtained even if only a proportion of the heavy mineral assemblage is counted. Only the presence of the mineral and not its relative abundance was recorded if there were less than 200 grains of each mineral per slide. Strong reflected light is necessary for examining the grains and under high power objectives two lamps are most helpful.

Unfamiliar minerals are subjected to the refractive index tests. Such a mineral is placed on a slide and immersed in a drop of liquid of known R.I. It is then placed on a petrological microscope and the Becke or indirect illumination tests applied. Since these tests are more easily carried out on thin fragments than near spherical grains, the mineral grain should be broken and then immersed in oil.

If necessary further optical tests can be performed at this stage to confirm the identification.

The following non-opaque minerals have been identified:- anatase, apatite, collophane, garnet, kyanite, monazite, rutile, sphene, staurolite, tourmaline, zircon.

Tourmaline is by far the most abundant, two-thirds of this mineral occuring as well rounded grains. Zircon was the next commonest, also mainly well rounded. These two minerals constitute 70-90% of the heavy minerals recorded in the Ellerslie Sandstone.

Besides the above non-opaque heavy minerals present in this formation,much opaque secondary mineral was present particularly in the form of limonite and pyrites. These contaminents, as far as the analysis is concerned, can be removed by treating the samples, firstly with hydrochloric acid to dissolve the limonitic material, and then with nitric acid to remove the pyrites. This was not done, however in this exercise, as it was preferred to record the apatite present, which would also have dissolved in the acids, and further the samples were collected from the core where little of this secondary material was present.

TABLE 8

Heavy Mineral Analysis of the Ellerslie Sandstone
from the Hudson's Bay et al 14-27-41-12 W4M Well.

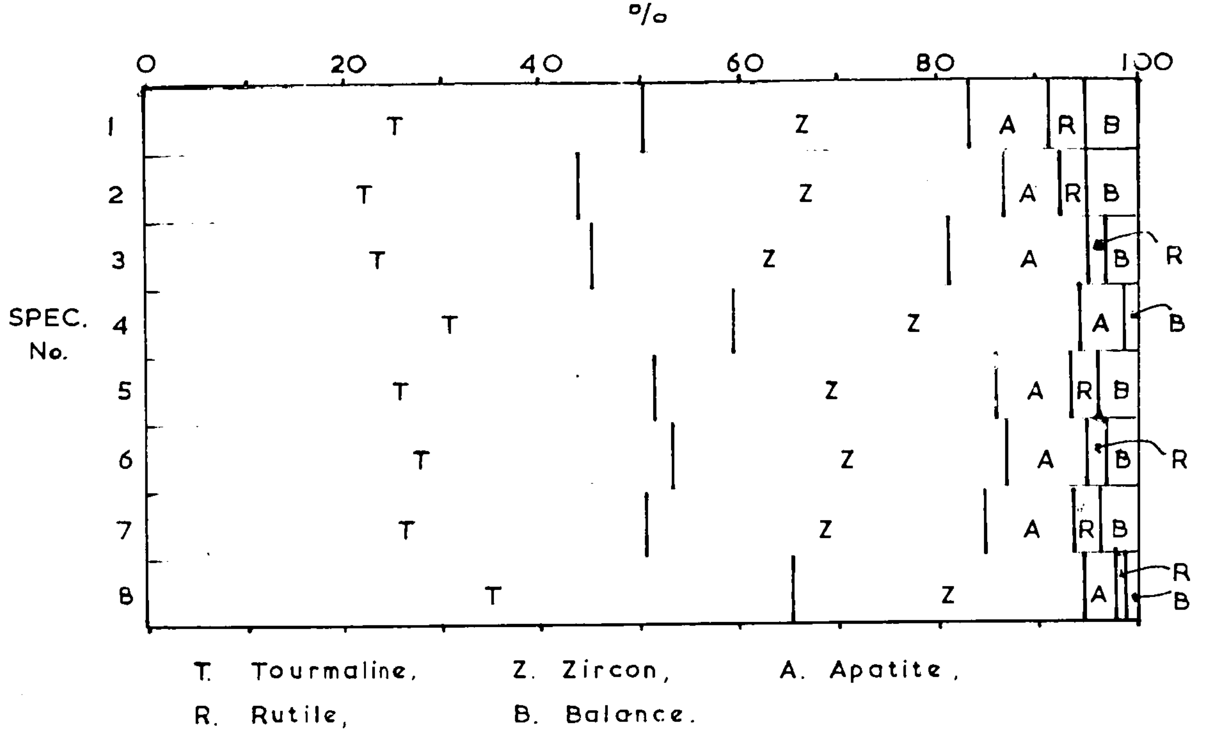
Heavy Mineral.	Core Specimen Number.							
	1.	2.	3.	4.	5.	6.	7.	8.
Anatase	Tr.	Tr.	-	Tr.	Tr.	-	Tr.	-
Apatite	C.	C.	C.	C.	C.	C.	C.	C.
Collophane	Tr.	Tr.	-	-	-	-	-	-
Garnet	R.	R.	Tr.	Tr.	R.	Tr.	-	-
Kyanite	-	Tr.	Tr.	-	-	-	-	-
Monazite	-	Tr.	-	-	-	Tr.	-	-
Rutile	C.	C.	R.	Tr.	C.	R.	C.	R.
Sphene	Tr.	Tr.	Tr.	-	Tr.	R.	Tr.	Tr.
Staurolite	Tr.	-	-	-	-	Tr.	R.	Tr.
Tourmaline	VA.	A.	A.	VA.	VA.	VA.	VA.	VA.
Zircon	A.	A.	A.	A.	A.	A.	A.	A.

Tr. (Trace) < ½% ; R. (Rare) = ½ - 3% ; C. (Common) = 3 - 20%;

A. (Abundant) = 20 - 50% ; VA. (Very Abundant) = > 50%.

FIGURE 25.

To show the Relative Abundance of the Heavy Accessory Minerals Represented in the Ellerslie Ss.



DESCRIPTION OF THE HEAVY MINERALS

1. Tourmaline:

Tourmaline, present in all of the samples studied, is the most abundant non-opaque heavy mineral species. In reflected light the grains are usually brown or yellowish-brown in colour, with a glassy lustre. Other colours noted are green, and less commonly colourless, pink, blue and dark coloured grains. Coloured species are strongly pleochroic, predominantly yellow to dark brown or black, also pink to dark green and black, and green to darker green. Grains are either well rounded, elongate prismatic with rounded terminations, or irregularly fractured fragments. Inclusions of opaque and non-opaque minerals are common, and in prismatic grains, often show allignment parallel to the length of the grain. Clear rounded overgrowths are developed on several grains. It is a typical mineral of acid plutonic igneous rocks and metamorphic rocks. (Photo. 34 Nos. 7 to 12 ; Photo. 35 No. 1).

2. Zircon:

This mineral ranks second to tourmaline in abundance as a non-opaque heavy mineral accessory in the Ellerslie Sandstone. It is almost always colourless, but a few yellow-brown and pale purple grains were observed. The grains are usually transparent, although the surfaces of some grains are frosted and appear translucent. Euhedral grains are found with slightly worn to rounded terminations, particularly in those showing prismatic habit. Well rounded, almost spherical or egg-shaped grains are also found, possibly suggesting more than one cycle of erosion. On the more worn samples, surface pitting is observed. Opaque and non-opaque mineral inclusions occur and occasionally zoning is seen. Zircon is characterised by its high refractive indices and high birefringence.

Although zircon has a hardness of 7½ on Moh's Scale, Poldervaart (1955) regards it as being one of the most resistant accessory minerals, to both chemical and mechanical attack. This apparent stability is accounted for by its comparative small size and general absence of cleavage. (Photo. 34 Nos. 1 to 6; Photo 35 No. 3).

3. Apatite:

Colourless apatite occurs as worn elongate prismatic and stubby prismatic grains, and as grains which are oval or nearly circular in plan. In transmitted light some of the apatite grains are seen to be transparent. However under reflected light most grains are found to have a frosted surface which gives a whitish colour. Apatite under reflected light, may at times be confused with colourless zircon, but this can be rectified by use of the petrological microscope and refractive index oils, as apatite possesses lower refractive indices and a weaker birefringence than the colourless zircon. Apatite is characterised by its detrital form. It has a hardness of five and consequently some grains are fractured, whilst other grains are rounded. The basal cleavage of apatite is exhibited by some grains and appears as cross fractures. It originates in acid plutonic rocks. (Photo. 34 Nos. 13, 14; Photo. 35 No. 2).

4. Staurolite:

This heavy mineral occurs as reddish-brown to yellow, flat, irregular grains. It shows faint pleochroism in shades of yellow, and it is weakly birefringent. Inclusions were rare. It is a typical metamorphic rock mineral.

5. Rutile:

This mineral is usually deep red-brown in colour under reflected light, but orange and yellow grains were also observed. The grains were generally translucent to nearly opaque and had an adamantine lustre. Irregular shaped grains were most common, although a few subangular and subrounded varieties were present. It is characterised by its high relief, deep colour and high birefringence. It shows the same colour between crossed polars as in ordinary light owing to its extreme birefringence. It originates from acid igneous and metamorphic rocks. (Photo. 34 No. 15).

6. Garnet:

Garnet occurs as colourless, pale pink, pale yellow, and occasionally deep red or brown grains. The surfaces of the grains are always etched, giving an angularity to their shape. The mineral is brittle and most grains are fracture fragments. This implies that they could not have been transported in this condition but represent the remnants of original garnets in the final stages of corrossion. They are characterised by high relief, isotropism, and irregular fracture. They are derived from metamorphic rocks. (Photo. 34 No. 16; Photo. 35 Nos. 4, 5).

Other Heavy Minerals:

Other heavy minerals recorded from the Lower Mannville in Alberta include anatase, collophane, kyanite, monazite and sphene. (Williams 1963, Mellon 1956).

The Stability of Heavy Minerals

The information available concerning the stability of heavy minerals appears to be somewhat contradictory. For example, Carroll (1953), states that the concensus of opinion suggests that zircon is the most stable heavy mineral. Yet in his own opinion he qualifies this statement by adding, "under acid conditions". In an alkaline environment, solution occurs in the presence of calcium bicarbonate and sodium carbonate solutions. Further, he point out that zircons are structurally weak at the edge between the prism and pyradmid faces, and because of their brittleness, they readily break into irregular fragments with conchoidal fracture. Tourmaline and rutile are held to be slightly less stable than zircon.

Some of the zircons have a frosted surface suggesting solution. The presence of solution pits may be due to inclusions, at least in part. Microfissures radiate from these inclusions and at these sites of local stress solubility will be greatest. Solution pits occur to a lesser extent in tourmaline and rutile.

The stability of apatite and garnet is also subject to conflicting views. Dryden (1946), believes garnet to weather more quickly than any other mineral species, whereas Goldich (1938), considers it to be stable. Raeside (1959), however states that iron rich garnets are the most prone to decomposition. Apatite is soluble in carbonated water according to Mackie (1923).

The garnets that occur in the heavy mineral separations are invariably etched to a greater or lesser extent, and some apatites were frosted, and this, it is inferred, was produced principally by circulating groundwaters during diagenesis. Apatite is regarded by most authorities as a vulnerable mineral.

According to Pettijohn (1954), there is no change in the frequency of occurrence of zircon and tourmaline with age, but garnet and apatite appear to be slightly more common in younger sediments. He therefore suggests that the two former are very stable minerals, whilst the latter are less stable.

The different varieties of the minerals, often indicated by differences in colour or by colour zoning, will no doubt have different stability ranges according to their composition, and this may partly account for the differing views expressed. Differences of environment will affect different minerals in different ways. Thus it is not sufficient to compare the relative abundance of heavy mineral percentages without trying to account for variations in these proportions. The explanation is however, most difficult, as the criteria are often not available in the rocks. Who is to say whether a mineral is absent due to non-deposition or to decomposition? However, a general statement into this realm will be attempted.

It is essential to know something about the conditions affecting solution. The difficulty here is that the older the sediment the more likely it is that these conditions have changed during its geological history. In the case of the Ellerslie Sandstone we are dealing with mineral grains which by their association are interpreted as having been derived from the acid igneous and metamorphic rocks typical of the Canadian Shield. But they might well be second or even third cycle sediments, at least in part. Since it is an alluvial accumulation the constituent material has been subject to corrasion and corrosion during transport, and the mineral grains were largely separated from the original rock fragments. And further, being such a porous and permeable rock the mineral grains have also been subject to intrastratal solution by circulating groundwaters.

The amount of solution may be reflected to some degree by the filling of pore spaces by post-depositional precipitation of secondary minerals, such as silica, calcium carbonate or iron rich minerals. This would give rise to a less permeable sandstone with reduced circulation as the interstices became occluded, but no rock thin section examined had every pore space filled with secondary material whether quartz, calcite, limonite or pyrites. The latter is produced by the original iron minerals such as magnetite going into solution, supplying material for iron concretions or cement. The reported occurrence of rare authigenic overgrowths of zircon and rutile in some heavy mineral suites implies that some of the original minerals have undergone partial solution and reprecipitation. Carroll has suggested that solution of a little zirconium and its association with siliceous solutions, in the correct proportions under stagnant conditions, seems to be all that is required to produce zircon overgrowths. This sequence of conditions is not difficult to imagine happening in isolated backwater areas of the Ellerslie River alluvial plain.

In summary then, it is apparent that intrastratal solution of minerals, which can mask or destroy the evidence of paragenesis provided by the heavy mineral assemblage, is a very complex factor. It depends on the nature of the mineral, the pH value of the interstitial solutions, the permeability of the rock, the velocity of flow of the groundwaters, the temperature of the groundwater, and the geological age of the formation. Unfortunately, a very detailed study of all these criteria may, only provide essentially, negative conclusions.

CONCLUSION AND ACKNOWLEDGEMENTS

It is hoped that some of the undergraduates of the department wondering to which field of Geology to apply themselves might gain some insight into the sphere of the Petroleum Geologist and benefit from reading this thesis.

The writer wishes to express his thanks to Professor K.C. Dunham for encouraging him to start this project with the above idea in mind. Sincere thanks are due to Dr. G.P. Larwood, my Supervisor in the Department of Geology, University of Durham, and to Dr. T.E. Smith, my colleague in the Geology Department, Sunderland Technical College, for their kindness in reading the original text and making helpful suggestions and criticisms. Gratitude is also expressed to colleagues in Canada for providing various material.

BIBLIOGRAPHY

References

1. ALLEN, J.R.L. - 1965. Fining upwards cycles in alluvial successions. Liv. and Manch. Geol. Jour. v.4, p.229-246.

2. BADGLEY, P.C. - 1952. Notes on the subsurface stratigraphy and oil and gas geology of the Lower Cretaceous Series in Central Alberta. Geol. Surv. Can., Paper 52-11.

3. BATES, C. and BATES, E. - 1960. Evaluation of heavy mineral separations using artificial samples. J. Sed. Pet. v.30, pp. 148-153.

4. BERNARD, H.A. and MAJOR, C.F. - 1963. Recent meander belt of the Brazos River; an alluvial "sand" model. Bull. Am. Assoc. Pet. Geol., v.47, pp. 350.

5. BOKMAN, J. - 1960. Oil gravities in the Western Canada basin. Jour. Alberta Soc. Pet. Geol., v.8, pp. 81-87.

6. BRODYLO, S. - 1964. Reservoir Engineering Digest, Calgary, Alberta. 3 vols.

7. BURST, J.F. - 1958. "Glauconite" pellets; their mineral nature and applications for stratigraphic interpretations. Bull. Am. Assoc. Pet. Geol., v.42, pp. 310-327.

8. BUSCH, D.A. - 1959. Prospecting for stratigraphic traps. Bull Am. Assoc. Pet. Geol. V.43, pp. 2829-2843.

9. CARRIGY, M.A. and MELLON, G.B. - 1964. Authigenic clay mineral cements in Cretaceous and Tertiary sandstone of Alberta. J. Sed. Pet., v.34, pp. 461-472.

10. CARROLL, D. - 1953. Weatherability of zircon. J. Sed. Pet., v.23, pp. 106-116.

11. CONYBEARE,C.E.B.-1964a.Oil Accumulation in Alluvial Stratigraphic Traps. Aust. Nat. Univ. Pub. No. 29.

12. CURRAY, J.R. and GRIFFITHS, J.C.- 1955. The spericity and roundness of quartz grains in sediments. Geol. Soc. Am. Bull., v.66, pp. 1075-1096.

13. DAPPLES, E.C. - 1947. Sandstone types and their associated depositional environments. J. Sed. Pet., v.17, pp. 91-100.

14. DAPPLES, E.C. - 1959. The behaviour of silica in diagenesis. Soc. Econ. Pal. and Min., Spec. Pub. 7, pp.36-54.

15. DAPPLES, E.C. - 1953. KRUMBEIN, W.C. and SLOSS, L.L. Petrographic and lithologic attributes. J. Geol., v.61, pp. 91-100.

16. DRYDEN, L. - 1946. Comparative rates of weathering of some

common heavy minerals. J. Sed. Pet. v.16, pp. 91-96.

17. FOLK, R.L. - 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. J. Geol., v.62, pp. 344-359.

18. FOLK, R.L. - 1956. The role of texture and composition in sandstone classification. J. Sed. Pet., v.26, pp. 166-171.

19. FRIEDMAN, G.M.- 1961. Distinction between dune, beach and river sands from their textural characteristics. J. Sed. Pet., v.31, pp. 514-529.

20. GLAISTER, R.P.- 1958. Petrology of Blairmore sandstones. Jour. Alberta Soc. Pet. Geol., v.6, pp. 43-49.

21. GLAISTER, R.P.- 1959. Lower Cretaceous of southern Alberta and adjoining areas. Bull. Am. Assoc. Pet. Geol., v.43, pp. 590-640.

22. GOLDICH, S. - 1938. A Study of Rock Weathering. Jour. Geol., v.46, pp. 17-58.

23. GORREL, H.A. - 1958. The importance of subsurface water data in petroleum geology. Preprint Pet. and Nat. Gas Div., Can. Inst. Min and Met., 9th Annual Tech. Mtg. Calgary.

24. GRAVENOR, C.P. - 1959. Heavy minerals of the Athabasca sandstone. Jour. Alberta Soc. Pet. Geol., v.7, pp. 1-6.

25. GRIFFITHS, J.C. - 1952. Grain size distribution and reservoir rock characteristics. Bull. Am. Assoc. Pet. Geol., v.36, pp. 205-229.

26. GUSSOW, W.C. - 1954. Differential entrapment of oil and gas, a fundamental principle. Bull. Am. Assoc. Pet. Geol., v.38, pp. 816-853.

27. HEALD, M.T. and RENTON, J.J. - 1966. Experimental studies of sandstone cementation. J. Sed. Pet., v.36, pp. 977-991.

28. HITCHON, B. - 1958. Preliminary report of a study of the regional variations in composition of crude oils, natural gases and formation waters in selected ancient basins of western Canada. Oil in Canada, v. 10, No. 48, pp. 22-28.

29. HODGSON, A.V. - 1958. The Viking Sand of the Consort-Provost area, Alberta. Sun Oil Company, Spec. Report No.27.

30. HODGSON, A.V. - 1958. The Viking Sand and the Banff Sand of the Sibbald area, Alberta. Sun Oil Company Spec. Report No. 29.

31. HODGSON, A.V. - 1959. The Bow Island Series and the Lower Cretaceous Sands of the Brooks area, Alberta. ibid. No. 34.

32. HODGSON, A.V. - 1959. The Viking and Lower Cretaceous Sands of the Bigstone area, Alberta. ibid. No. 36.

33. HODGSON, A.V. - 1960. The Viking and Basal Quartz Sands of east-central Alberta. ibid. No. 40.

34. HODGSON, G.W. - 1954. Vanadium, nickel and iron trace metals in crude oils of western Canada. Bull. Am. Assoc. Pet. Geol. v.38, pp. 2537-2554.

35. HODGSON, G.W. - 1959. Geochemical aspects of petroleum migration in Pembina, Redwater, Joffre and Lloydminster oil fields, Alberta, Canada. Bull. Am. Assoc. Pet. Geol., v.43, pp. 311-328.

36. HUBBERT, M.King- 1953. Entrapment of petroleum under hydrodynamic conditions. Bull. Am. Assoc. Pet. Geol., v.37, pp. 1954-2026.

37. HUME, G.S. and HAGE, C.O. - 1941. The gology of east-central Alberta. Can. Geol. Surv. Mem., No. 232.

38. HUNT, C.W. - 1950. Preliminary report on the Whitemud oil field, Alberta, Canada. Bull. Am. Assoc. Pet. Geol., v.34, pp. 1795-1801.

39. HUTTON, C.O. - 1950. Studies of heavy detrital minerals. Bull. Am. Geol. Soc., v.61, pp. 635-710.

40. KRUMBEIN, W.C. - 1941. Measurement and geologic significance of shape and roundness of sedimentary particles. J. Sed. Pet., v.11, pp. 64-72.

41. KRYNINE, P.D. - 1946. The tourmaline group in sediments. Jour. Geol., v.46, pp. 65-87.

42. LAND, L.S. and HOYT, J.H. - 1966. Sedimentation in a meandering estuary. Sedimentology, v.6, No. 1, pp. 1-33.

43. LATUS, T.J. - 1966. Developments in western Canada in 1965. Bull. Am. Assoc. Pet. Geol., v.50, pp. 1281-1294. (Annual Review).

44. LAYER, D.B., et al, - 1949. The Leduc Oilfield, Alberta. ibid. v.33, pp. 572-602.

45. LERBEKMO, J.F. - 1961. Porosity reduction in Cretaceous sandstones of Alberta. Jour. Alberta Soc. Pet. Geol., v.9, pp. 192-199.

46. LEVORSEN, A.I. - 1966. The obscure and subtle trap. Bull. Am. Assoc. Pet. Geol., v.50, pp. 2058-2067.

47. LINK, T.A. - 1951. Source of oil in "Tar Sands" of Athabasca River, Alberta, Canada. Bull. Am. Assoc. Pet. Geol., v.35, pp. 854-864.

48. LOCKWOOD, R.P. & ERDMANN, M. - 1959. Oil in Canada, v.11, pp. 19-25.

49. LORANGER, D.M. - 1951. Useful Blairmore microfossil zone in central and southern Alberta, Canada. Bull. Am. Assoc. Pet. Geol., v.35, pp. 2348-2367.

50. MACKIE, W. - 1923. The Sources of Purple Zircons in the Sedimentary Rocks of Scotland. Trans. Geol. Soc. Edin., v.11, pp. 200-213.

51. McBRIDE, E.F. - 1963. A classification of common sandstones. J. Sed. Pet., v.33, pp. 664-669.

52. MEINSCHEIN, W.G.-1959. The origin of petroleum. Bull. Am. Assoc. Pet. Geol., v.43, pp. 925-943.

53. MELLON, G.B. and WALL, J.H. - 1956. Geology of the McMurray formation. Research Council Alberta, Reot. No. 72.

54. " " - 1961. Correlation of the Blairmore Group and equivalent strata. Edmonton Geol. Soc. Quart., v.5, No. 1.

55. NAUSS, A.W. - 1945. Cretaceous stratigraphy of Vermilion area, Alberta, Canada. Bull. Am. Assoc. Pet. Geol. v.29, pp. 1605-1629.

56. PASTERNACK, D.S.-1951. and CLARK, K.A. The components of the bitumen in Athabasca bituminous sands. Alberta Research Council Rept., No. 58.

57. PETTIJOHN, F.J.- 1954. Classification of sandstones. J. Geol., v.62, pp. 360-365.

58. POLDERVAART, A.- 1955. Zircons in rocks: 1 Sedimentary rocks. Am. Jour. Sci., v.253, pp. 432-461.

59. POWERS, M.C. - 1953. A new roundness scale for sedimentary particles. J. Sed. Pet., v.23, pp. 117-119.

60. RAESIDE, J. - 1959. Stability of Index Minerals in Soils with particular reference to Quartz, Zircon and Garnet. J. Sed. Pet., v.29, pp. 493-502.

61. REIKER, R.E. - 1962. Hydrocarbon fluorescence and migration of petroleum. Bull. Am. Assoc. Pet. Geol., v.46, pp. 60-75.

62. ROBSON, D.A. - 1956. A sedimentary study of the Fell Sandstones of the Coquet Valley, Northumberland. Q.J.G.S., v.112, pp. 241-262.

63. RUBEY, W.W. - 1951. Geologic history of sea water. Bull. Geol. Soc. Amer., v.62, pp. 1111-1148.

64. RUDOLPH, J.C. - 1959. The Bellshill Lake field, Alberta, Canada. Bull. Am. Assoc. Pet. Geol., v.43, pp. 880-897.

65. SABINS, F.F. - 1963. Anatomy of a stratigraphic trap, Bisti Field, New Mexico. ibid., v.47, pp. 193-228.

66. SABINS, F.F. - 1963. Computer flow diagram in facies analysis. ibid., v.47, pp. 2045-2047.

67. SAXENA, S.K. - 1966. Evolution of zircons in sedimentary and metamorphic rocks. Sedimentology, v.6, pp. 1-33.

68. SCOTT, J. COLLINS, G.A. and HODGSON, G.W. - 1954. Trace metals in the McMurray oil sands and other Cretaceous reservoirs of Alberta. Can. Inst. Min. and Met. Trans., v.57, pp. 34-40.

69. SLOSS, L.L. - 1962. Stratigraphic models in exploration. Bull. Am. Assoc. Pet. Geol., v.40, pp.1050-1057.

70. SPENCER, D.W. - 1963. The intrepretation of grain size distribution curves of clastic sediments. J. Sed. Pet., v.33, pp. 180-190.

71 TAYLOR, J.M. - 1950. Pore space reduction in sandstones. Bull. Am. Assoc. Pet. Geol., v.34, pp. 701-716.

72. THOMPSON, A.F. - 1959. Pressure solution and porosity; in Silica in Sediments. Soc. Econ. Pal. and Min., Spec. Pub. No. 7, pp. 92-110.

73. THOMPSON, A. - 1956. Factors in loss of porosity by quartzose sandstones of Virginia. Bull. Am. Assoc. Pet. Geol., v.40, pp. 2286-2287.

74. WALDSCHMIDT,W.A.-1941. Cementing materials in sandstones and their influence on migration and accumulation of oil and gas. ibid., v.25, pp. 1839-1879.

75. WELLER, J.M. - 1959. Compaction of sediments. Bull. Am. Assoc. Pet. Geol., v.43, pp. 273-310.

76. WHITE, D.E. - 1963. Chemical composition of subsurface waters. HEM, J.D. & WARING, G.A. U.S. Geol. Surv. Prof. Paper 440-F.

77. WICKENDEN, R.T.D. - 1948. The Lower Cretaceous of the Lloydminster oil and gas area, Alberta and Saskatchewan. Geol. Surv. Can. Paper 48-21.

78. WILLIAMS, G.D.C.-1962. Potassium-argon mineral dates from the Mann- BAADSGAARD, H. and ville Group. Jour. Alberta Soc. Pet. Geol., STEEN, G. v.10, pp. 320-325.

79. " " - 1963. The Mannville Group (Lower Cretaceous) of Central Alberta. Bull. Can. Pet. Geol., v.11, pp. 350-368.

80. WORKMAN, L.E. - 1959. The Blairmore Group in the sub-surface of Alberta. Alberta Soc. Pet. Geol. Guidebook, Ninth Ann. Field Conf. pp. 122-129.

81. WRIGHT, M.D. - 1959. The formation of cross bedding by a meandering or braided stream. J. Sed. Pet., v.29, pp. 610-615.

82. WYATT, M. - 1954. Zircons as provenance indicators. Amer. Min., v.39, pp. 983-990.

Books

83. CAROZZI, A.V. "Microscopic Sedimentary Petrography", 1960, J. Wiley and Sons.

84. KRUMBEIN, W.C. and PETTIJOHN, F.J. "Manual of Sedimentary Petrography", 1938, Appleton Century, New York.

85. LEOPOLD, L.B. WOLMAN, M.G. and MILLER, J.P. "Fluvial Processes in Geomorphology", 1964, Freeman & Co., San Fransisco.

86. LeROY, L.W. "Subsurface Geologic Methods", 1951, Colorado School of Mines, Golden, Colorado.

87. LEVORSEN, A.I. "Geology of Petroleum", 1954, Freeman and Co., San Fransisco.

88. McCROSSAN, R.G. and GLAISTER, R.P. ed., "Geological History of Western Canada", 1964, Alberta Soc. Pet. Geol.

89. MILNER, H.B. "Sedimentary Petrography", 1952, 3rd ed., Allen and Unwin, London.

90. PETTIJOHN, F.J. "Sedimentary Rocks", 1957, 2nd ed., Harper, New York.

91. POTTER, P.E. and PETTIJOHN, F.J. "Palaeocurrents and Basin Analysis", 1963, Springer-Verlag, Berlin, Gottingen, Heidelberg.

92. van STRAATEN, L.M.J.U., ed., "Deltaic and Shallow Marine Deposits", Proc. Sixth Int. Sed. Cong. of 1963, Elsevier,

London, 1964.

93. WEEKS, L.G. "Origin, migration and occurrence of petroleum", chap. 5, in Petroleum Exploration Handbook, 1961, McGraw-Hill, New York.

94. WILLIAMS, H. TURNER, F.J. and GILBERT, C.M. "Petrography: an introduction to the study of rocks in thin sections". 1954, Freeman and Co., San Fransisco.

Symposia

95. "Geology of Sand and Sandstone", by F.J. Pettijohn, P.E. Potter, and R. Siever. Conference sponsored by Indiana Geological Survey, 1965.

96. "Geometry of Sandstone Bodies", Am. Assoc. Pet. Geol. Symp. 1961.

97. "Habitat of Oil", ibid., 1958.

98. "Oil Fields of Alberta", Alberta Soc. Pet. Geol., 1960.

HITCHON, B, and SHAW, D.R., Regional variations in the properties of formation fluids in Alberta. de MILLE, G., Regional habitat of oil bearing formations in Alberta. pp. 23.

99. "Second Athabasca Oil Sands Conference, Edmonton, K.A. Clarke Volume, Alberta Research Council. 1963.

HITCHON, B., Composition and formation fluids in strata above and below the pre-Cretaceous unconformity in relation to the Athabasca Oil Sands. pp. 63-74.

POW, J.R., FAIRBANKS, G.H., and ZAMORA, W.J., Descriptions and reserve estimates of the oil sands of Alberta. pp. 1-14.

100. "Soc. Econ. Pal. and Min. Symp., Toronto, 1964".

VISHER, G.S., Fluvial processes as interpreted from ancient and recent fluvial deposits.

101. "The Tectonics of the Canadian Shield", Royal Soc. Can., Spec. Pub. No. 4, ed. J.S. Stevenson, 1962.

SPROULE, J.C., The Tectonics of the Canadian Shield and adjoining sedimentary basins in relation to oil and gas occurrences. pp. 108-118.

102. "Third Canadian Hydrology Symp. Proc., Calgary", 1962.

Le BRETON, E.G., and JONES, J.F. A regional picture of the groundwater chemistry in particular aquifers of the western plains.

103. "21st Int. Geol. Cong., Copenhagen, part 1, 1960.

BACK, W., Origin of hydrochemical facies of groundwater in the Atlantic coastal plain. pp. 87-95.

104. "Western Canada Sedimentary Basin", Am. Assoc. Pet. Geol. 1954.

Maps and Data Sheets

105. "Lexicon of Geologic Names in Western Canada Sedimentary Basin and Arctic Archipelego. 1960. Alberta Soc. Pet. Geol., Spec. Pub.

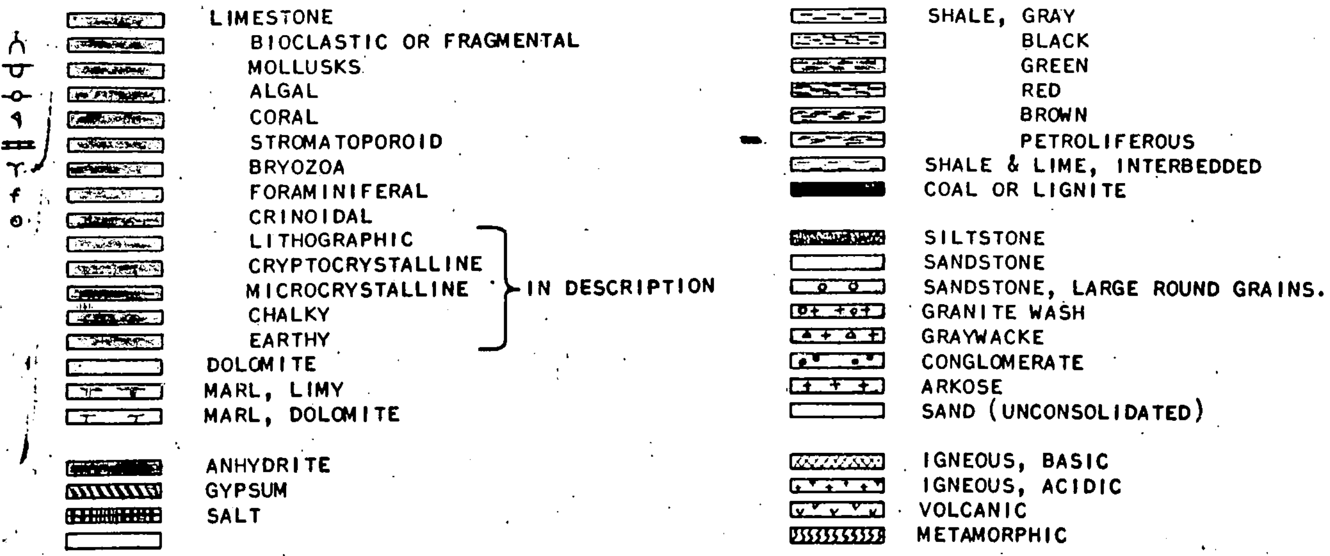
106. "Oil and Natural Gas Developments, 1965-66". Annual review oil and gas field map and data. Canadian Bank of Commerce, Petroleum and Natural Gas Department, Calgary, Alberta.

107. "Palaeozoic Subsurface Contour Map for Area Five, Alberta. Oil and Gas Conservation Board, Calgary, Alberta.

LITHOLOGIC SYMBOLS

FIGURE 26.

ROCK TYPES



LIMESTONE
    BIOCLASTIC OR FRAGMENTAL
    MOLLUSKS
    ALGAL
    CORAL
    STROMATOPOROID
    BRYOZOA
    FORAMINIFERAL
    CRINOIDAL
    LITHOGRAPHIC
    CRYPTOCRYSTALLINE
    MICROCRYSTALLINE
    CHALKY
    EARTHY
    (LITHOGRAPHIC – EARTHY: IN DESCRIPTION)
DOLOMITE
MARL, LIMY
MARL, DOLOMITE

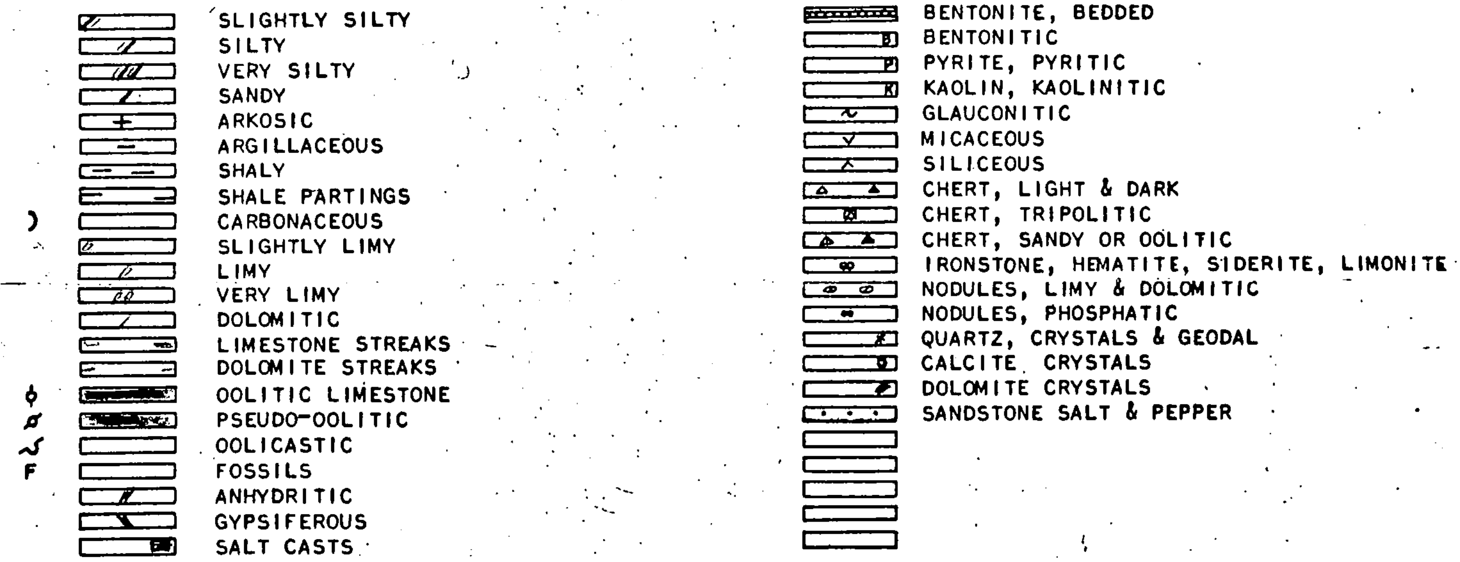
ANHYDRITE
GYPSUM
SALT

SHALE, GRAY
    BLACK
    GREEN
    RED
    BROWN
    PETROLIFEROUS
SHALE & LIME, INTERBEDDED
COAL OR LIGNITE

SILTSTONE
SANDSTONE
SANDSTONE, LARGE ROUND GRAINS.
GRANITE WASH
GRAYWACKE
CONGLOMERATE
ARKOSE
SAND (UNCONSOLIDATED)

IGNEOUS, BASIC
IGNEOUS, ACIDIC
VOLCANIC
METAMORPHIC

COMBINATIONS AND ACCESSORIES



SLIGHTLY SILTY
SILTY
VERY SILTY
SANDY
ARKOSIC
ARGILLACEOUS
SHALY
SHALE PARTINGS
CARBONACEOUS
SLIGHTLY LIMY
LIMY
VERY LIMY
DOLOMITIC
LIMESTONE STREAKS
DOLOMITE STREAKS
OOLITIC LIMESTONE
PSEUDO-OOLITIC
OOLICASTIC
FOSSILS
ANHYDRITIC
GYPSIFEROUS
SALT CASTS

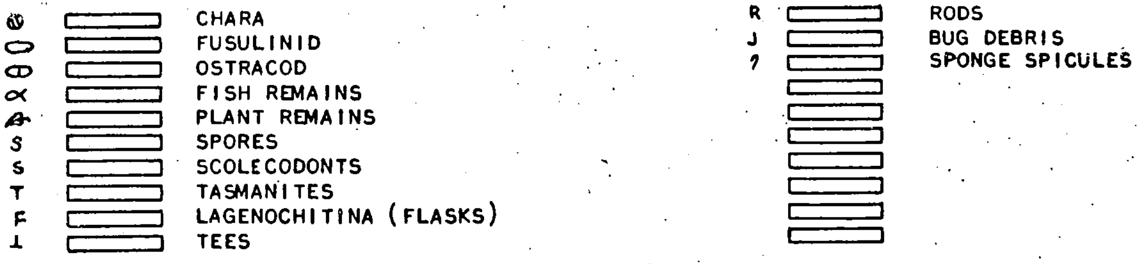
BENTONITE, BEDDED
BENTONITIC
PYRITE, PYRITIC
KAOLIN, KAOLINITIC
GLAUCONITIC
MICACEOUS
SILICEOUS
CHERT, LIGHT & DARK
CHERT, TRIPOLITIC
CHERT, SANDY OR OOLITIC
IRONSTONE, HEMATITE, SIDERITE, LIMONITE
NODULES, LIMY & DOLOMITIC
NODULES, PHOSPHATIC
QUARTZ, CRYSTALS & GEODAL
CALCITE CRYSTALS
DOLOMITE CRYSTALS
SANDSTONE SALT & PEPPER

MISCELLANEOUS

CAVINGS, CANNOT INTERPRET

NO CORE AVAILABLE
NO SAMPLE
NO SAMPLE AVAILABLE

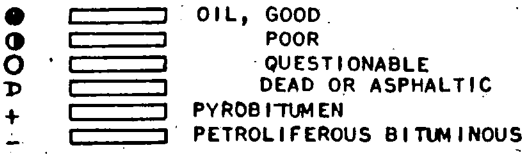
FOSSILS



CHARA
FUSULINID
OSTRACOD
FISH REMAINS
PLANT REMAINS
SPORES
SCOLECODONTS
TASMANITES
LAGENOCHITINA (FLASKS)
TEES

RODS
BUG DEBRIS
SPONGE SPICULES

SHOWS



OIL, GOOD
    POOR
    QUESTIONABLE
    DEAD OR ASPHALTIC
PYROBITUMEN
PETROLIFEROUS BITUMINOUS


1.


2.


3.

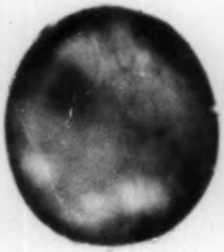

4.


5.


6.

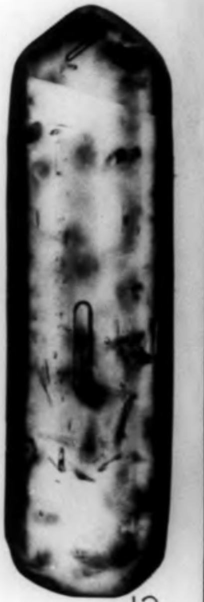

7.


8.


9.


10.


11.


12

1 mm.


13.


14.


15.

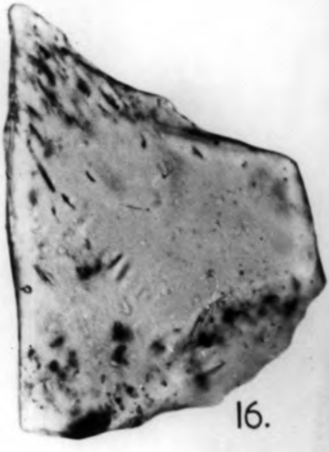
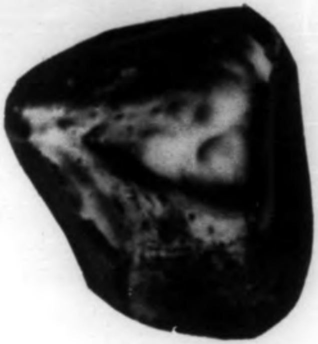

16.

Photo. 34.

Heavy Minerals x112.5, Ordinary light.

1 - 6 Zircon, 7 - 12 Tourmaline, 13, 14 Apatite,
15 Rutile, 16 Garnet.



1.

2.

3.

1 mm.

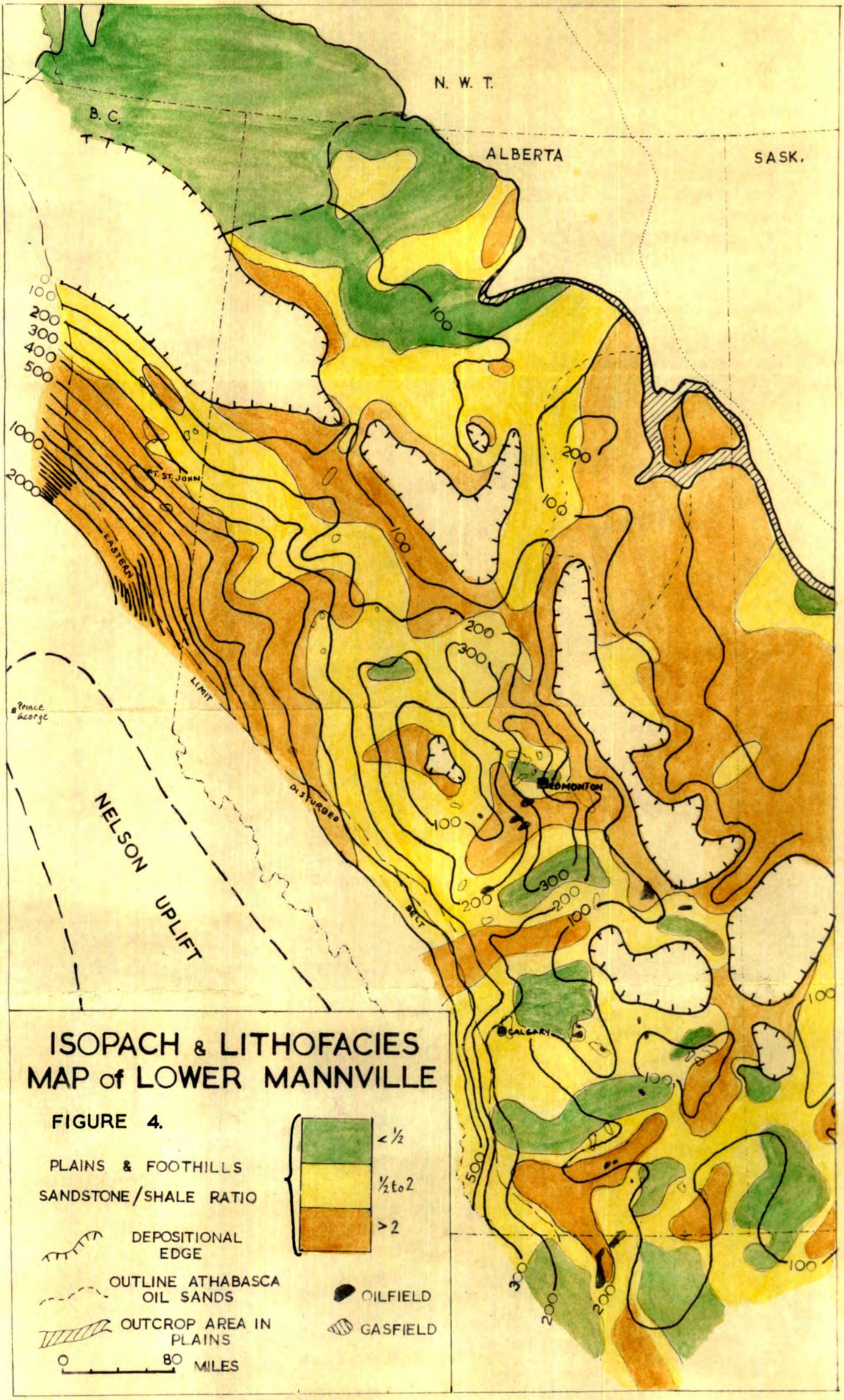
4.

5.

Photo. 35.

as Photo. 34.

1 Tourmaline, 2 Apatite, 3 Zircon,
4, 5 Garnet.

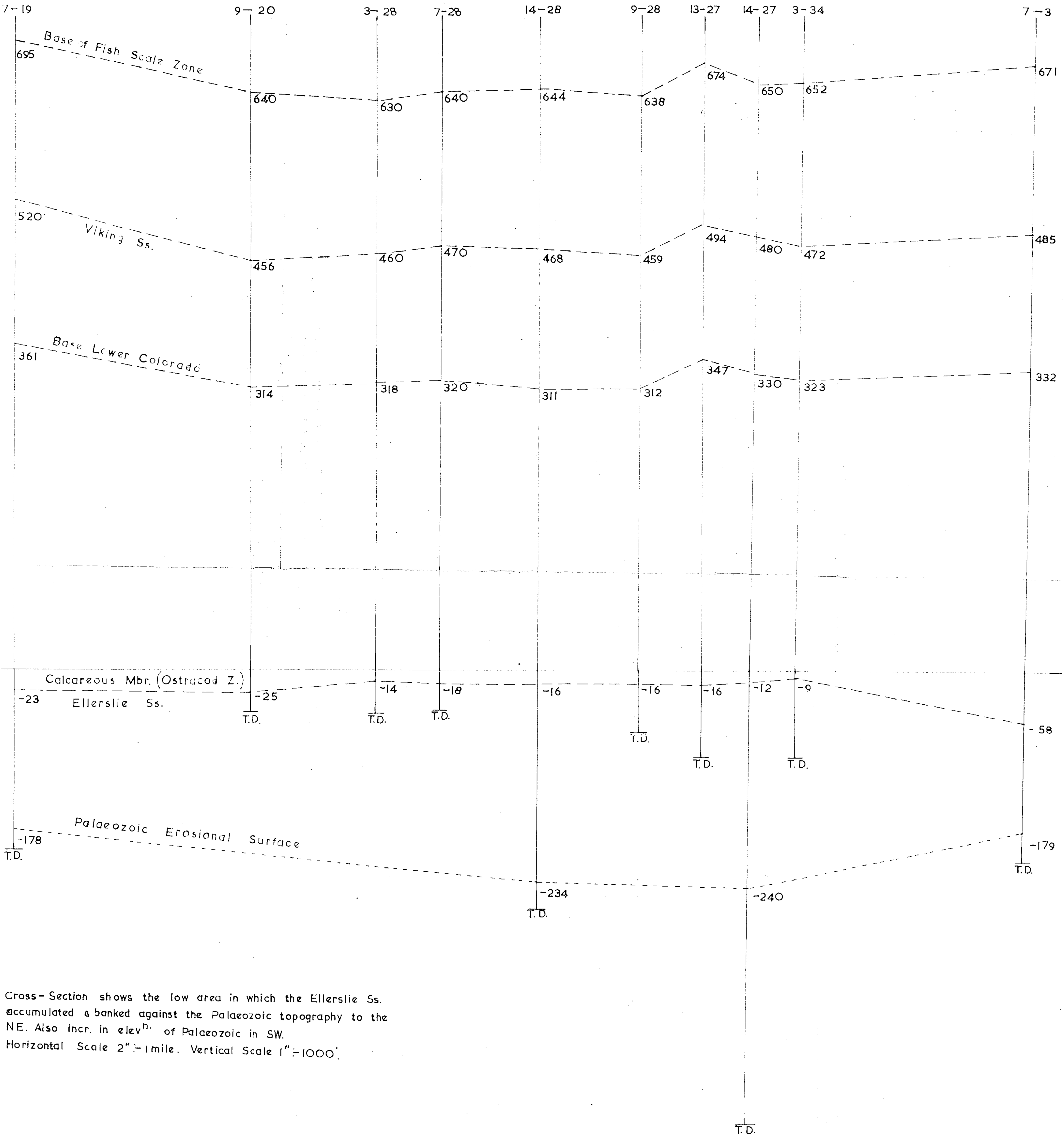


ISOPACH & LITHOFACIES MAP of LOWER MANNVILLE

FIGURE 4.

FIGURE 18.

CROSS-SECTION 1a. W/ TOP OF CALCAREOUS MEMBER (OSTRACOD ZONE) AS DATUM.



Cross-Section shows the low area in which the Ellerslie Ss. accumulated & banked against the Palaeozoic topography to the NE. Also incr. in elev$^{n.}$ of Palaeozoic in SW.
Horizontal Scale 2" = 1 mile. Vertical Scale 1" = 1000'.

FIGURE 24.

MECHANICAL ANALYSIS CUMULATIVE CURVES, ELLERSLIE SANDSTONE, BELLSHILL LAKE.

e.g. HUDSON'S BAY . et al BELLSHILL LAKE #14-27-41-12 W4M.

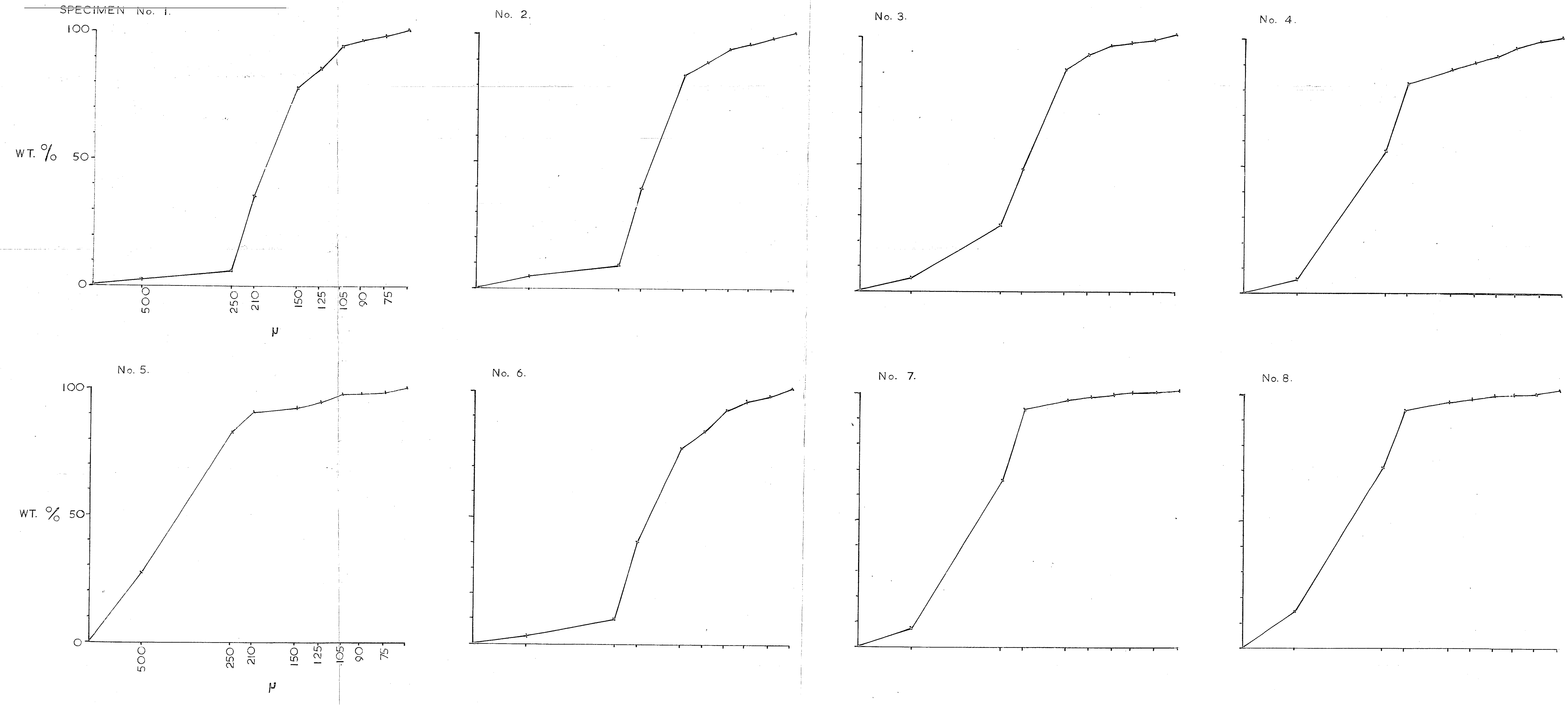
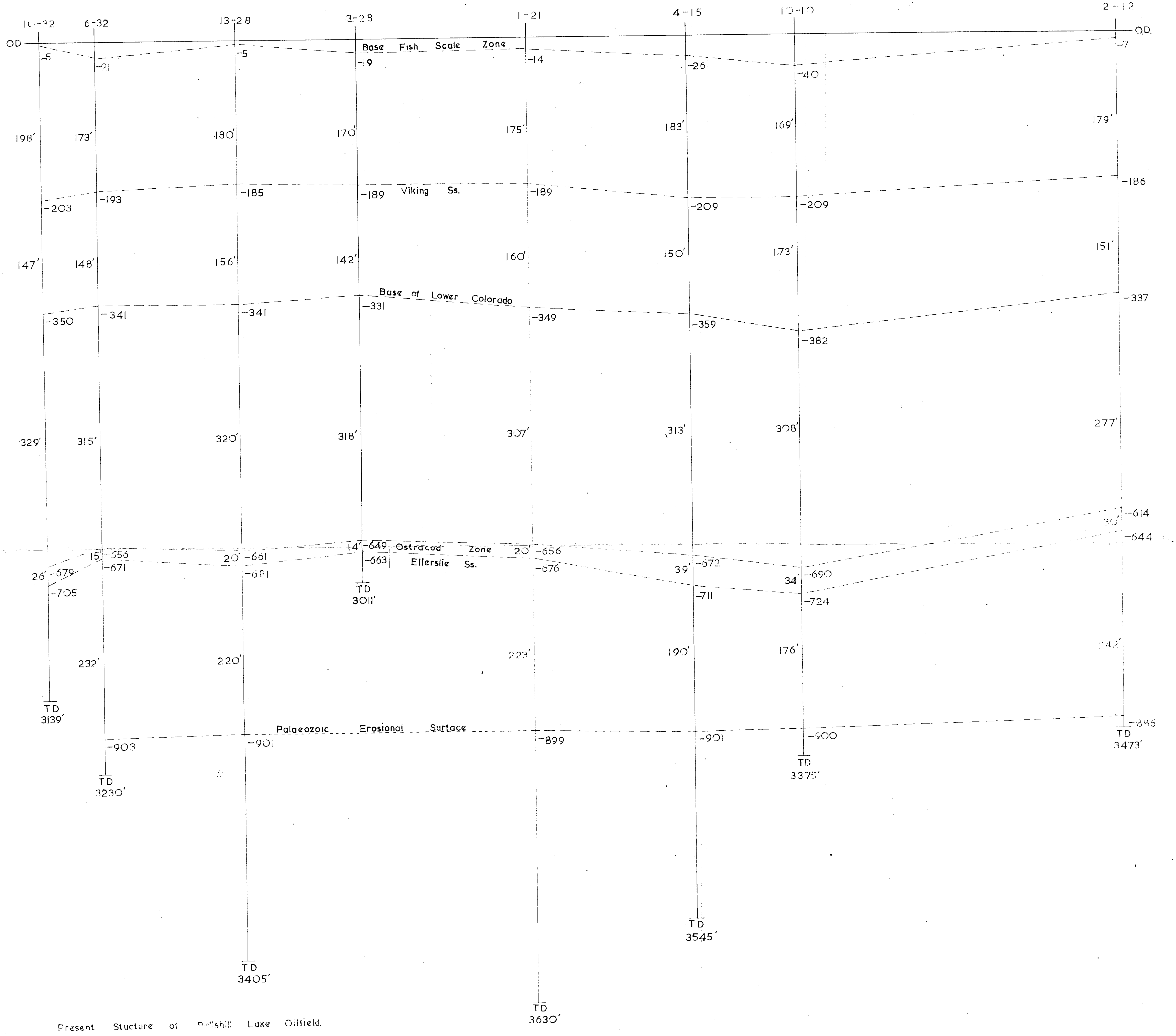


FIGURE 19.

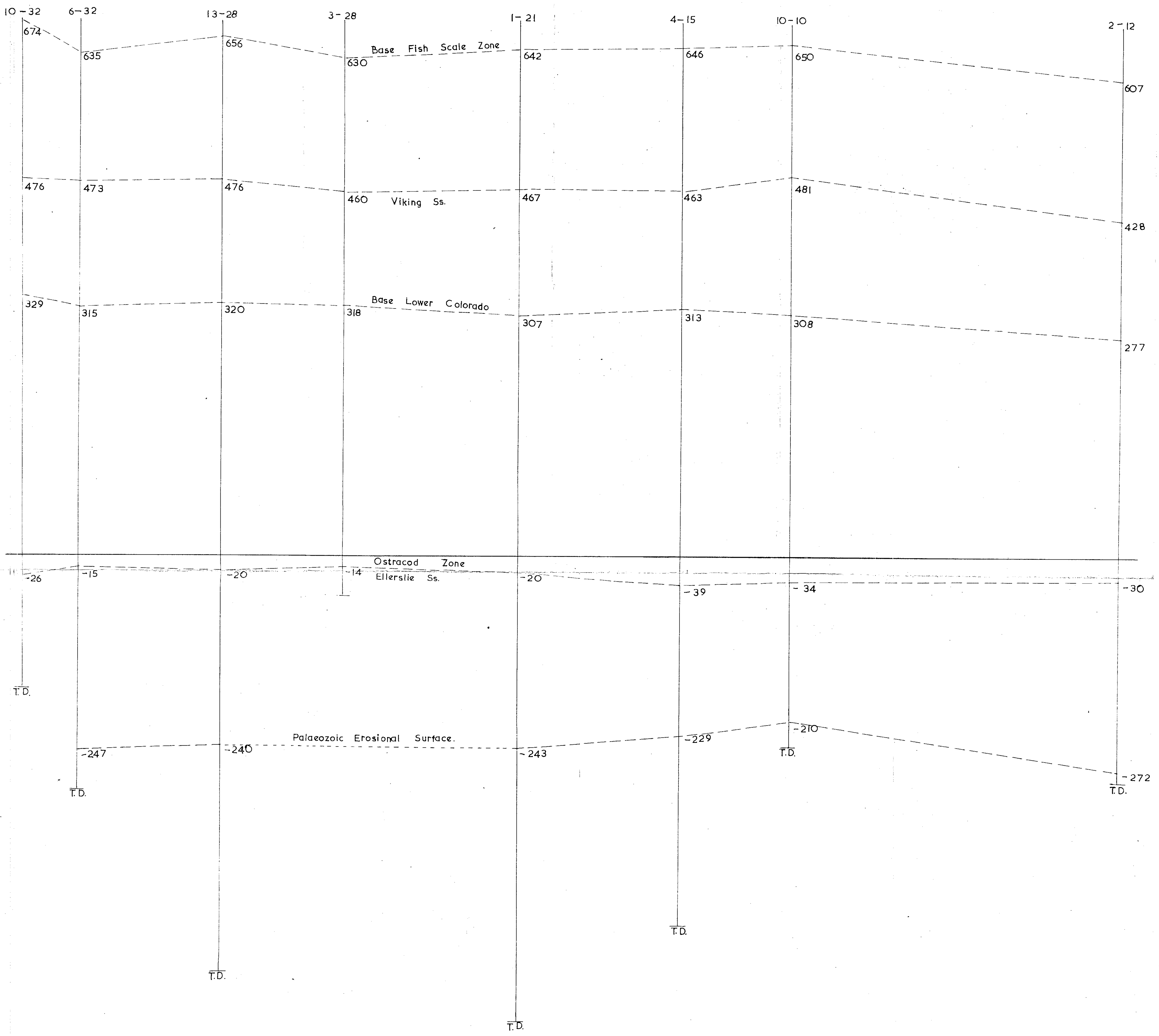
CROSS - SECTION 2. W/OD. AS DATUM



Present Stucture of Bellshill Lake Oilfield.
Cross - Section NW - SE indicates a good development of Ellerslie Ss. irrespective of absence, of hydrocarbon (2-12).
Horizontal Scale 2": 1 mile. Vertical Scale 1" : 1000 ft.

FIGURE 20.

CROSS-SECTION 2a. W/ TOP OF CALCAREOUS MEMBER (OSTRACOD ZONE) AS DATUM. (STRUCTURE SHOWN ON ELLERSLIE Ss. ± AS DEPOSITED & SIMILARLY THE PALAEOZOIC RELIEF.)



This Cross-Section NW—SE shows the ± uniform thickness of the sandstone, even where no hydrocarbon is found. (2-12) Ostracod zone time was terminated by a short marine transgression.
The thickening of the Ostracod zone indicates increase in shale : sand ratio and thus greater compaction of the sand body.
Horizontal Scale 2":- 1 mile. Vertical Scale 1":- 1000'

FIGURE 23.

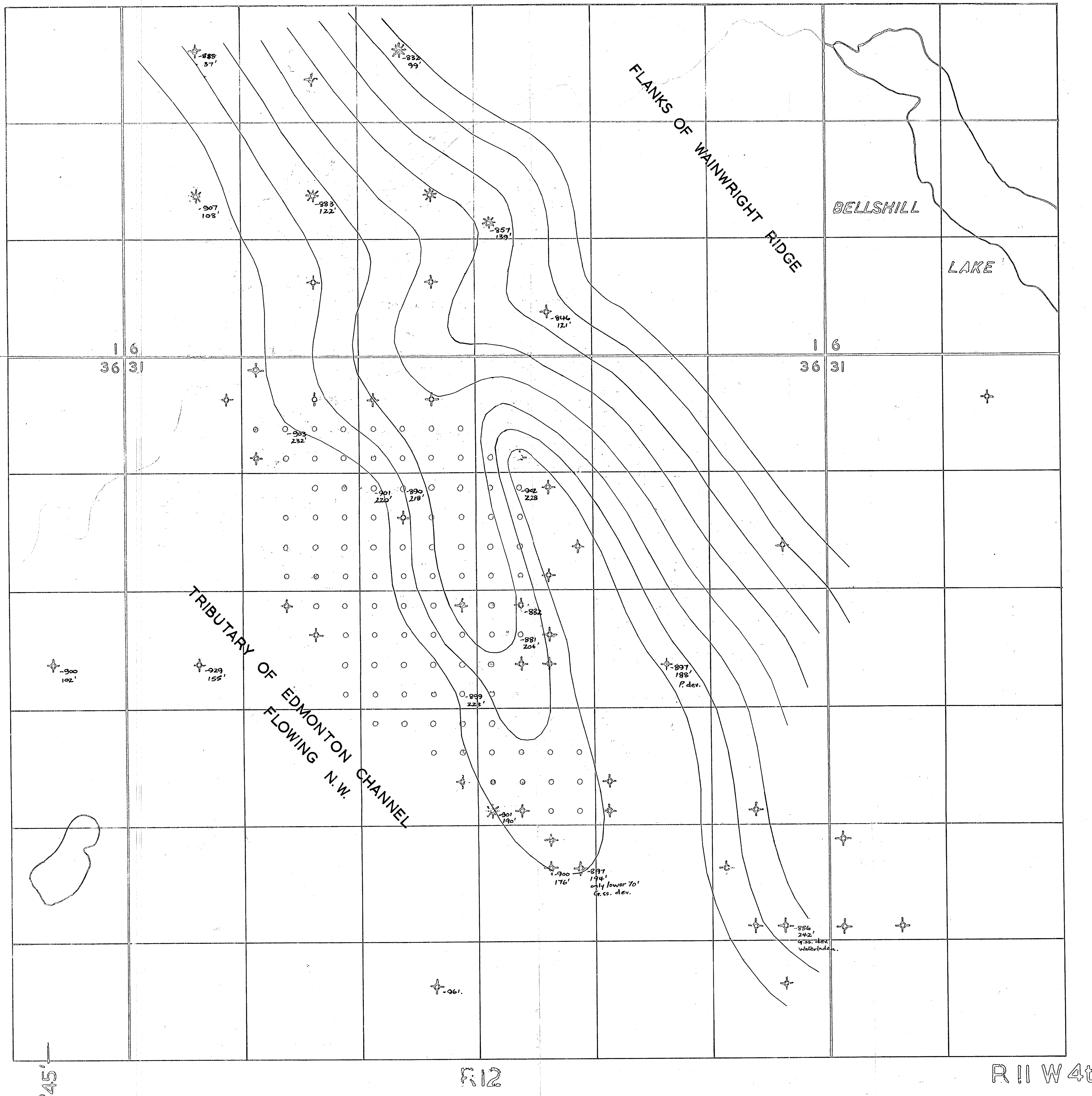
MECHANICAL ANALYSIS HISTOGRAMS of ELLERSLIE Ss. BELLSHILL LAKE.

e.g. HUDSON'S BAY et al BELLSHILL LAKE # 14-27-41-12 W4

STRATIGRAPHIC CROSS-SECTION THROUGH THE BELLSHILL LAKE OILFIELD AREA

FIGURE 21, CROSS SECTION 3.

BELLSHILL LAKE OILFIELD AREA



WELL REFERENCE

-✧- ABANDONED WELL

○ OIL WELL

○ LOC. OR DRILLING

✲ GAS WELL

SCALE 2" to 1 MILE

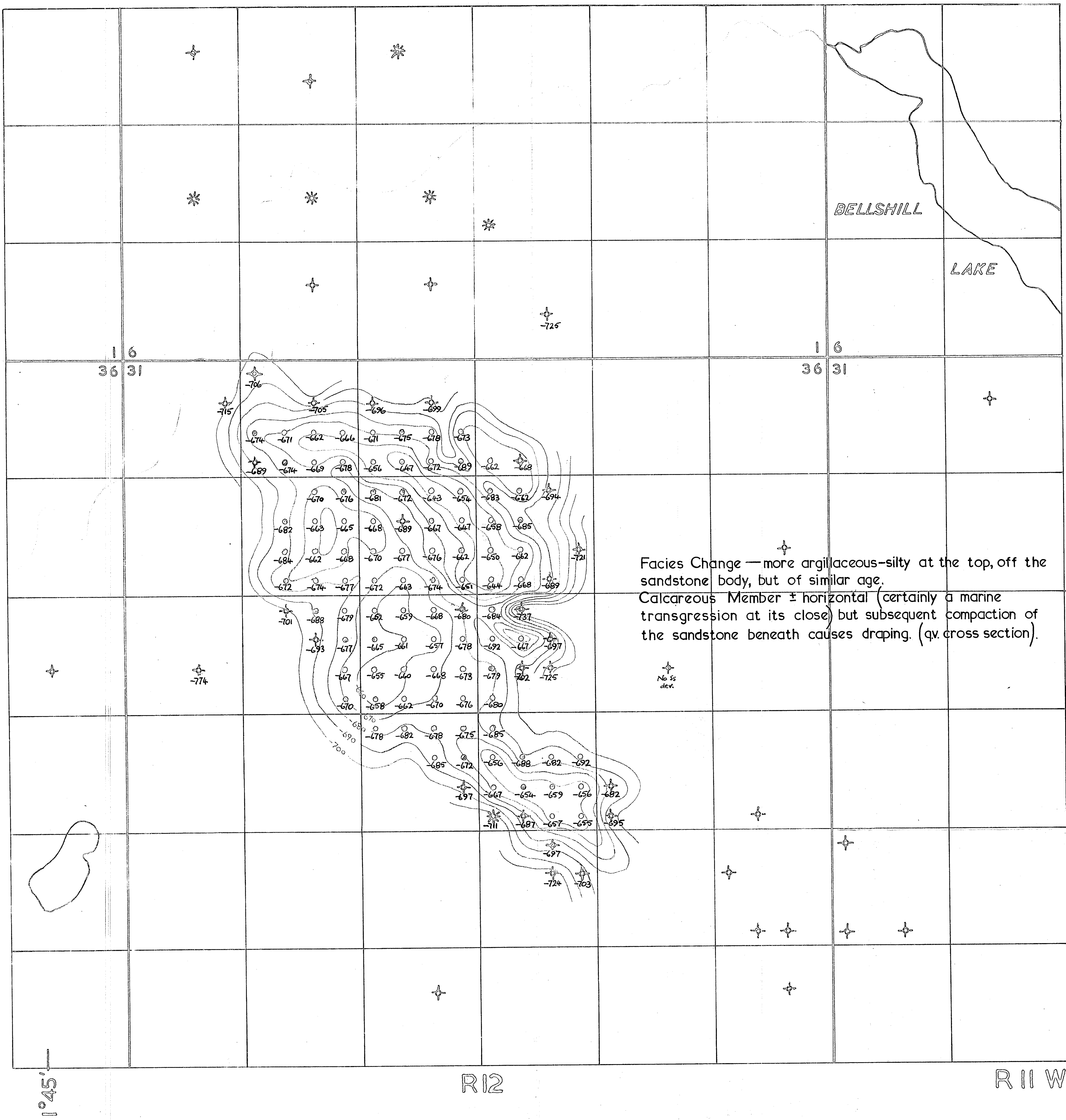
STRUCTURE CONTOUR MAP OF TOP OF THE PALAEZOIC UNCONFORMITY

Gross thickness of Ellerslie S.S. shown in feet

Contours 10 feet intervals.

FIGURE 13.

BELLSHILL LAKE OILFIELD AREA



Facies Change — more argillaceous-silty at the top, off the sandstone body, but of similar age.
Calcareous Member ± horizontal (certainly a marine transgression at its close) but subsequent compaction of the sandstone beneath causes draping. (q.v. cross section).

WELL REFERENCE

- ⌖ ABANDONED WELL
- ○ OIL WELL
- ○ LOC. OR DRILLING
- ✳ GAS WELL

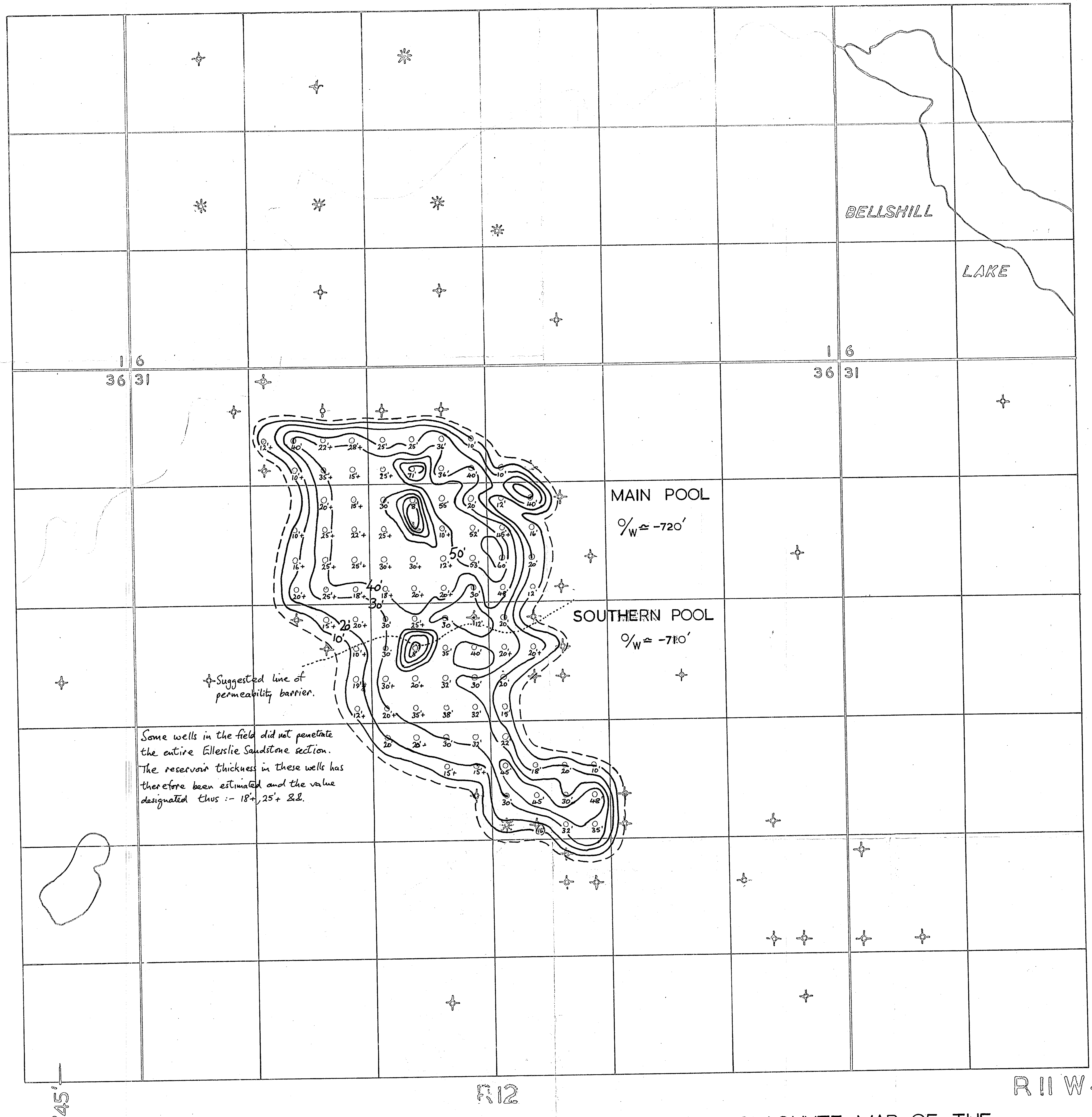
SCALE 2" to 1 MILE

STRUCTURE CONTOUR MAP OF TOP OF ELLERSLIE SANDSTONE

CONTOURS 10 FT. INTERVAL.

FIG

BELLSHILL LAKE OILFIELD AREA



Suggested line of permeability barrier.

Some wells in the field did not penetrate the entire Ellerslie Sandstone section. The reservoir thickness in these wells has therefore been estimated and the value designated thus :- 18+, 25+ &c.

NET PAY ISOPACHYTE MAP OF THE ELLERSLIE Ss.

10' INTERVAL

FIGURE

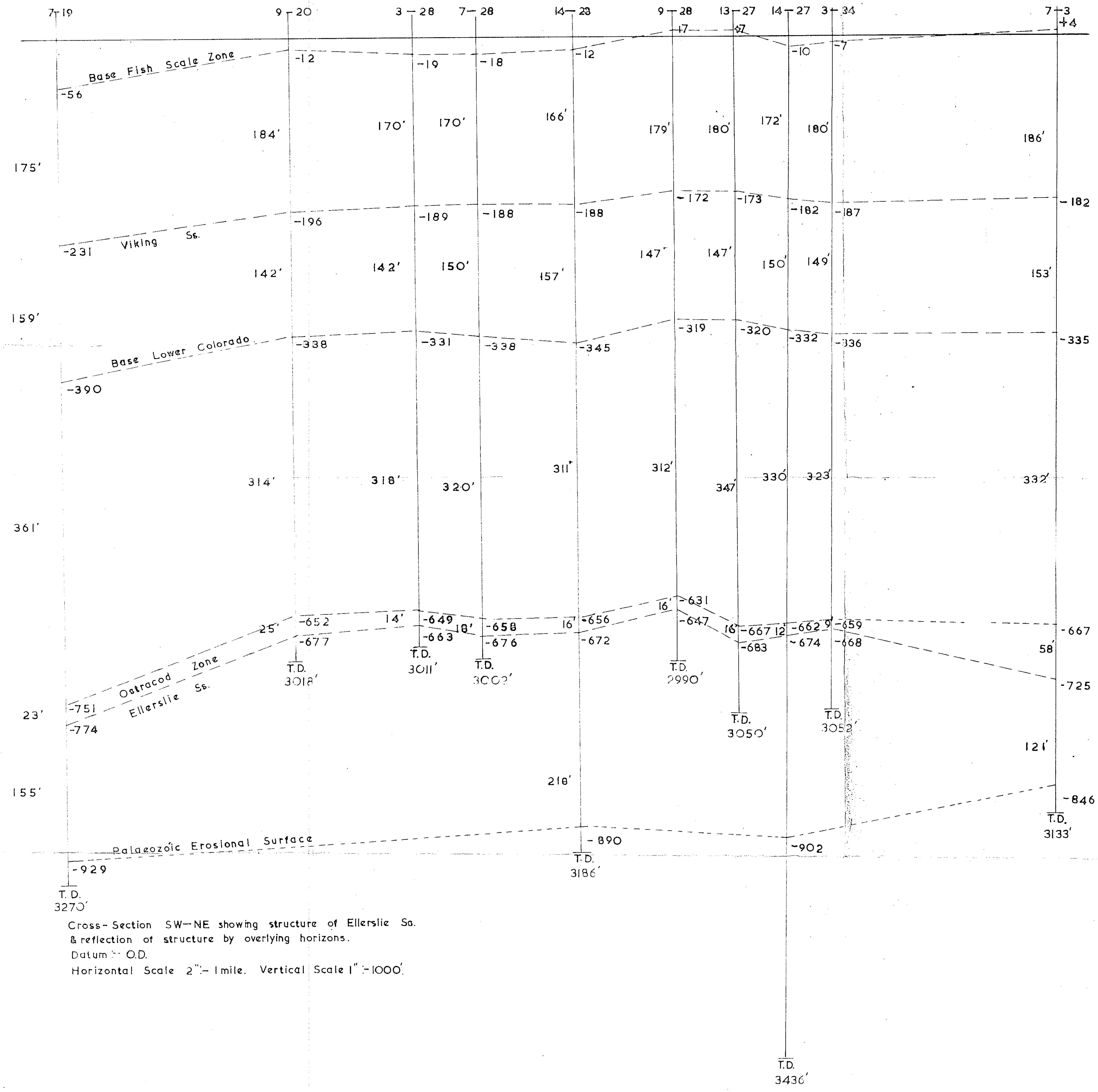
WELL REFERENCE

- ✧ ABANDONED WELL
- ○ OIL WELL
- o LOC. OR DRILLING
- ✹ GAS WELL

SCALE 2" to 1 MILE

FIGURE 17.

CROSS-SECTION I. W/ O.D as DATUM (PRESENT DAY STRUCTURE ON THE BELLSHILL LAKE OILFIELD & DRAPE OF THE OVERLYING BEDS.)



Cross-Section SW—NE showing structure of Ellerslie Ss. & reflection of structure by overlying horizons.
Datum :- O.D.
Horizontal Scale 2":- 1 mile. Vertical Scale 1":-1000'.

STRATIGRAPHIC CORRELATION CHART.