THE DEVONIAN GILWOOD SANDSTONE OF THE ATHABASCA RIVER AREA

ALBERTA, CANADA

(A Sedimentological Study, Based on Subsurface Data)

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P. W. SMIT

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Proefschrift ter verkrijging van de graad van doctor in de landbouwwetenschappen, op gezag van de Rector Magnificus, dr H. C. van der Plas, hoogleraar in de organische scheikunde, in het openbaar te verdedigen op Vrijdag 10 April, 1981 des namiddags vier uur in de aula van de Landbouwhogeschool te Wageningen.

STELLINGEN

1. De invloed van de beginnende opening van de Atlantische Oceaan is mogelijk reeds kenbaar in verschillen in de sedimentatie aan de W- en E- zijde van het Noord Amerikaanse continent sinds het begin van het Boven Carboon.

   S. Taber, 1927, Fault troughs, Journ. Geol., Vol. 37, No 7, p.577-606.

   R.G. McCrossan and J. W. Porter, 1973, The geology and petroleum potential of the Canadian sedimentary basins, — A synopsis, Can. Soc. Petrol. Geol., Memoir #1, p.589-720.

2. Het kwarts, dat groeit in een visceus medium, zoals een intrusief magma of een kalkmodder, neemt een sferulitische vorm aan.

3. Het ontbreken van planktonische foraminiferen in het Mesozoicum van de Canadese Arktische Eilanden kan verklaard worden door het ontbreken van de "Noord Atlantische Drift".

4. De maximale prijs, die de O.P.E.C. landen voor hun olie kunnen vragen, wordt bepaald door de kosten om synthetische olie te produceren.

5. In de "tar sands" worden de grootste concentraties van "tar" in het onderste gedeelte van het lagenpakket gevonden.

6. Voor de ontginning van de "tar sands" in West Canada zou de invoering van de Nederlandse baggertechnologie een milieu-vriendelijk en economisch alternatief zijn van de thans toegepaste Duitse technologie, die gebruik maakt van graafwielen en draglines.

7. Een verdubbeling van de netto prijs, die de oliemaatschappijen voor aardolie krijgen, kan tot een vertienvoudiging van de ontginbare voorraden leiden.

8. Een bezorgdheid, tegenovergesteld aan die naar voren gebracht door Baillie omtrent de universitaire opleiding van geologen in Canada, kan voor de Nederlandse opleiding worden geopperd.

   A.D. Baillie, 1979, The petroleum geologist — scientist or technician?, Bull. Can. Petrol. Geol., Vol. 27, No. 3, p.267-272.

9. De opmerking van Mawdsley en Byers, dat: "The english language has characteristics of adequacy and precision possessed by few others and the geologist and engineer will find it can meet his every need", is betwistbaar.

   J.B. Mawdsley and A.R. Byers, 1947, Notes on report writing for geologists and mining engineers, University of Saskatchewan, Dept. of Geology.

P.W. SMIT, 1981

ABSTRACT:

The Gilwood Member of de Watt Mountain Formation (upper Middle Devonian) in the Athabasca River area of central Alberta, Canada consists of a deltaic deposit fringing the emergent Peace River Arch and West Alberta Ridge. Paleotopography reconstruction techniques, trend analysis on the sandstone isolith and detailed well log examination, used to obtain the paleogeography of the deposits, show a system of submerged ridges, which radiate from the uplands into the Elk Point Basin, influencing the depositional pattern in the northern part of the area. They cause the existence of a quiet lagoonal area north of Twp. 60 and west of Rge. 10 W5M. [1] A thick (20 metre or more) sequence of coarse clastic material, belonging to a prograding delta complex, covers the Cambrian and Middle Devonian strata. Finer grained deposits occupy the eastern part of the lagoon. Outside this protected area, an agitated open marine environment has prevented the formation of extensive delta complexes. Tidal currents, sweeping into the Elk Point Basin from the north have possibly built up the barrier bars in which the Nipisi and Mitsue oilfields (Twp. 76-81, Rges. 1-7 W5M and Twp. 67-73, Rges. 3-6 W5M respectively) have been found. A northwesterly running counter current in the area south of Twp. 60, has transported the available sediments and redeposited them as bars off the coast. Data derived from core study and petrographic investigations reveal that the Gilwood Sandstone originated from two different source areas: the Peace River Arch and the West Alberta Ridge. The Peace River Arch consists of metamorphic and igneous rocks, while the West Alberta Ridge consists of Cambrian sediments. The climate during the Watt Mountain deposition has been inferred as tropical, causing deep weathering of the exposed surface associated with extensive leaching of the weathered zone. The deposition of coarse clastics ceased as the uplands became planated. A following transgression has been interrupted by two periods of stillstand or slight regression. The Watt Mountain Fm. is believed to be diachronous in the vicinity of the Peace River Arch and West Alberta Ridge. Evaporites and carbonates of the younger Fort Vermilion Formation have been deposited in shallow lagoons and embayments on the abandoned Gilwood delta complexes.

[1]For an explanation of the terms used in the survey system (e.g. Twp., W5M) see Appendix 1, Page 59.

TABLE OF CONTENTS

PAGE NO.

INTRODUCTION

Study Area

This study analyses the depositional history of a part of the Gilwood Member of the Watt Mountain Formation (upper Middle Devonian), encountered only in the subsurface of West-Central Alberta and a portion of northeastern British Columbia. This area, the Athabasca River area, was selected because:

1) In the geology of Alberta the area occupied an important position during the changes that occurred at the close of the Middle Devonian;
2) The lack as yet of a comprehensive geological analysis of the area;
3) The high density of available drilling information, and the interest in the area by the oil and gas industry.

This study has also been undertaken to test the usefulness of three techniques in subsurface geology; the trend analysis of isolith data; spontaneous potential log character; and the paleotopographic reconstruction technique.

The 82,500 km^2 study area is located between the 5th and 6th Meridian (114° and 118° W. respectively) and Twps. 40 and 75 (52° 30' N and 55° 20' N respectively) in West-Central Alberta, Canada. The area measures approximately 330 km north-south and 250 km east-west. The area has been named after the Athabasca River, a prominent feature which runs diagonally through the area from the southwest to the northeast corner. The area is centered around a point 175 km west-northwest of Edmonton, the capital of the Province of Alberta.

Previous Work

Guthrie (1956) has first defined the Gilwood Member. He has applied the name to a quartzose sandstone with grain sizes ranging from silt to gravel with occasionally thin, very coarse conglomerate beds. Thin, green shale interbeds are common. Guthrie's section has been obtained from the Stanolind Giroux Lake #1 well (6-20-65-20 W5M), later designated as the type section. Suska (1963) has included the Gilwood in the known geology of that time in a paper which covered the northern part of the Athabasca River area. Kramers & Lerbekmo (1967) and Shawa (1969) have reported on Gilwood sedimentation in relative small areas in the extreme northeast corner of the present study area. Recently a Geological Survey of Canada bulletin dealing with the upper Middle and lower Upper Devonian in the northern part of the study area has been published (Jansa and Fischbuch, 1974). The Watt Mountain Formation outside the study area has been described by many authors and the formation can be traced from the southern part of the Northwest Territories through N.E. British Columbia, Alberta, Saskatchewan and Manitoba into the United States (N.E. Montana and North Dakota).

Geological History

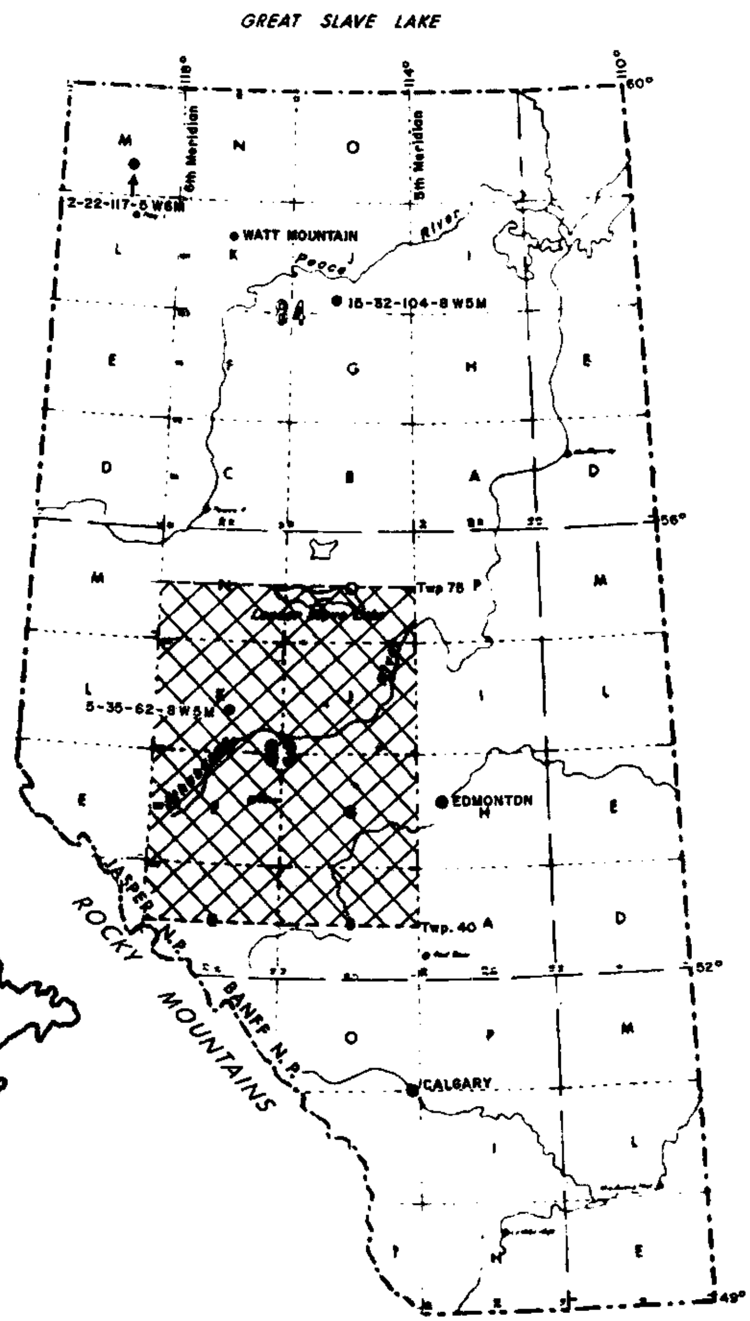
The regional-geological framework in which this study belongs, has been outlined by McCrossan and Glaister (eds.), (1964) and by Basset and Stout (1967). Paleogeographical analysis shows that during the last stages of the Middle Devonian two positive areas have dominated the deposition in the Athabasca River area: the Peace River Arch and the West Alberta Ridge (in the north and west respectively). The Peace River Arch, a complex of igneous and metamorphic rocks, has been a positive feature since, at least, the Upper Cambrian. This area has been rejuvenated several times.

The Arch underwent times of uplift and erosion during the last part of the Middle Devonian thereby shedding coarse clastics over an elliptically shaped area of variable width around it. The West Alberta Ridge has been a positive area since the end of the Cambrian (Pugh, 1973). The ridge is composed mainly of sedimentary rocks of Cambrian age. The southward extension of the West Alberta Ridge has as yet not been defined from well data. It is believed, that the ridge connects the Peace River Arch in the north with the Sweet Grass Arch in South Alberta near the present Canada-U.S. border. The amount of detritus which the ridge has shed during its existence is not well known, but it is generally believed that it has been less than the amount of detritus shed by the Peace River Arch during the same time span.

Figure 1

INDEX MAP

LOCATION OF STUDY AREA



North, east and south of the Peace River Arch and the West Alberta Ridge a shallow sea existed. During the Givetian, carbonates and evaporites were deposited. These deposits are thought to be tidal flat deposits (Jansa and Fischbuch, 1974). Against this paleogeographic background the events that followed when the Arch and Ridge were reactivated and became emergent must be visualized. The reactivation is recognizable throughout the whole of the Southern Interior Plains (Douglas et al, 1970). In the western part of the study area, the upper limit of the Muskeg Formation is unconformable, and in the eastern part of the area disconformable, as a result of these movements. An illustration of this is given in Table 1. Green and varicoloured shales of the Watt Mountain Formation have been deposited over the unconformity-disconformity surface. Close to the Peace River Arch and the West Alberta Ridge the coarser clastic sediments of the Gilwood Member prevail over the shales. Two depocenters for the sand facies are evident; one north of the Arch in the Manning and adjacent areas (Twps. 90-100, Rges. 20 W5M-12 W6M), where over 45 m. of sand, silt, and clay has been deposited; and the other south of the Arch in the Athabasca River area, where, on the average, a 15 m. sequence exists. The latter area has been selected for closer study since drilling has been considerably more intensive.

Methods of study

General:

The Gilwood member of the Watt Mountain Formation is not known to outcrop in Western Canada, therefore all data used in this paper are derived from well information, such as well logs, drill cuttings, and cores. About 1,550 wells drilled in the study area reached the Watt Mountain Formation. Many of them, however, penetrated only the top few feet. Approximately 700 wells penetrated the entire Watt Mountain Formation, bottoming out in older formations. The Watt Mountain Formation has been cored in about 120 wells. The wells drilled in the Mitsue oilfield, located in the northeast corner of the study area have not been included.

The energy resources legislation in the Province of Alberta required oil and gas companies to release to the general public all data, such as well logs, drill cuttings, cores, drillstem test results, production tests, etc. after a maximum of one year for exploratory wells and after 30 days for development wells. The Energy Resources Conservation Board (E.R.C.B.), the agency in charge of enforcing the conservation regulations and required to supervise the exploration and production of oil and gas, demands a complete set of well logs, drill cuttings, and all cores from each well drilled in the Province of Alberta. The E.R.C.B. has an excellent storage facility for drill cuttings and cores where these are accessible for public examination.

The following types of well logs are available to the public:

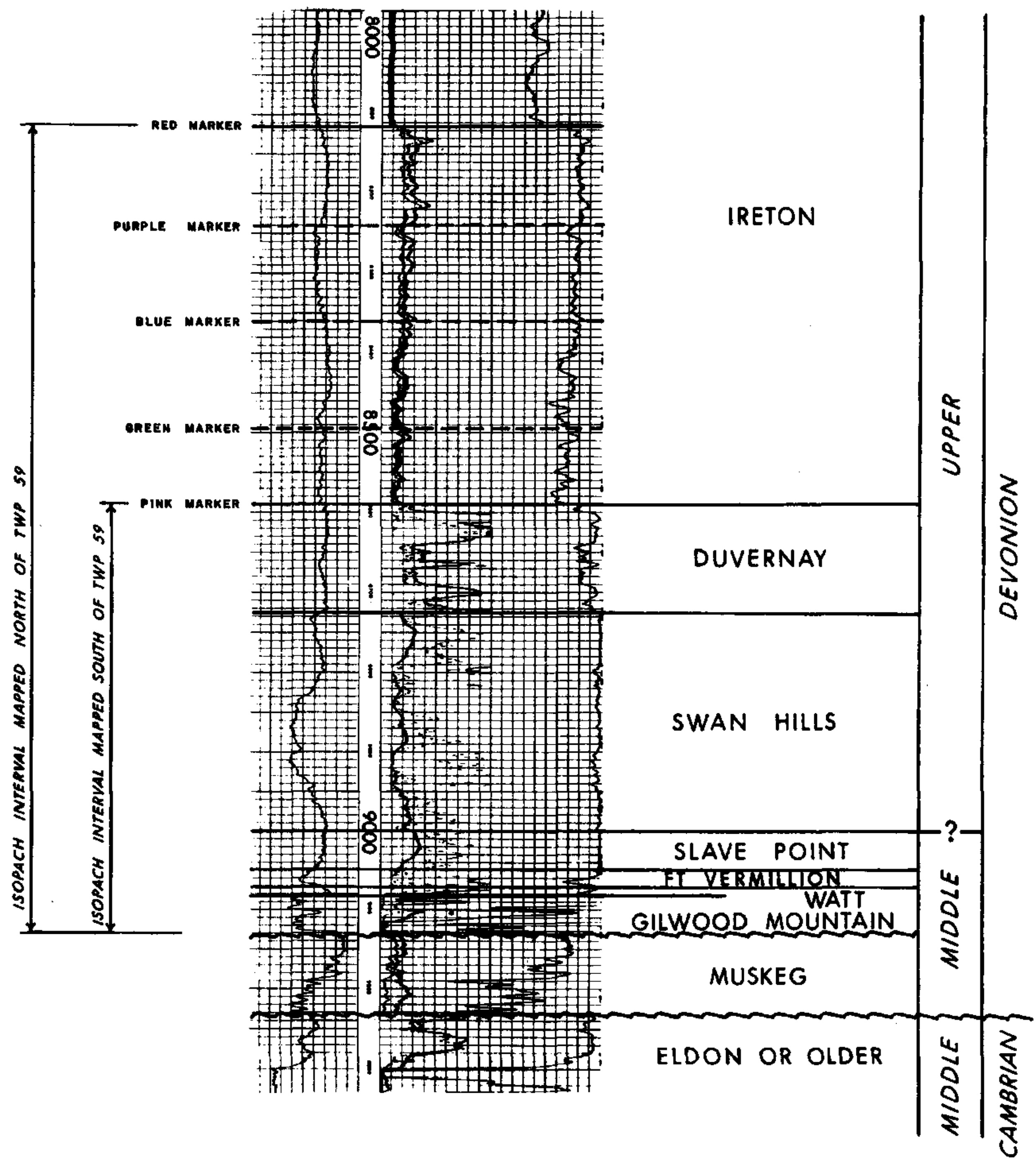
1. Resistivity Logs: Prior to 1960 the Electric Logs (E), since 1960 the Induction Electrical Log (I.E.S.) and/ or the Dual Induction Laterolog (D.I.L.)
2. Radiation Logs: Prior to 1955 the Gamma-Ray-Neutorn Logs, since 1955 the Gamma-Ray-Sonic Log.

These two log types are available for almost all of the wells in the study area. Wells drilled prior to 1950 have only the E-Log available. Other logs, such as Formation Density Log and the Sidewall Neutorn/Porosity Log, are run in wells drilled since 1970. In this study both resistivity and radiation logs have been used for gross lithology determination. Drill cuttings are sampled every three metres (10 feet) and, at best, are a reflection of the lithology penetrated by the drilling bit over this three metre interval. When used in conjunction with well logs, however, a fairly reliable picture of each 3 metre interval can be obtained, especially for grain size, mineral composition, cement and porosity types. Unfortunately sedimentary structures are usually destroyed by the action of the rotary drilling tools, thus drill cuttings cannot be used to accurately determine the environment of deposition. Cores are considered the best tools in the study of rocks. In many cases they are more useful than outcrop sections. A nine cm. (3.5 inch) diameter cylinder of clean, unweathered rock, in many instances cut lengthwise (slabbed), often shows perfectly all the rock properties and sedimentary structures. This study has started with the determination of the shape and thickness of the deposit. This is facilitated by the availability of mechanically derived data such as logs as opposed to the scarcity of other data such as cores. The shape of a deposit gives an indication for the general environment of deposition, such as delta, or alluvial fan. All available types of well logs are used to determine the shape parameter. The next step in the study consisted of spotchecks, using cores to test the validity of the conceptual sedimentary model obtained during the first step.

A. Paleotopography

The paleotopography on which the Gilwood sandstone was deposited has been reconstructed. The reconstruction has been achieved via an isopach map of the deposits between a "timelithologic" marker bed and the base of the Watt Mountain. Although bentonite beds, derived from volcanic ash are deposited in a less restricted environment than other sedimentary rocks and represent a short-lived event over a broad area, they are not encountered in the study area. Other marker beds which are environment controlled, such as thin limestone beds, used in this study, could not be recognized in wells with a reef type build-up. As Busch (1971) notes, thin limestone beds are deposited parallel to and adjacent to successive positions of a shoreline. These carbonate beds are extensive in area. A set of five thin carbonate beds within the Upper Devonian (Frasnian) Ireton shale sequence were selected (Fig. 2). During the deposition of the five carbonate beds the study area was a shallow sea and the carbonates represent five stages of relative stillstand (Busch, 1971 pp. 11-15). These five beds could be recognized throughout the entire area and the maximum isopach variation between the top and bottom beds does not exceed 15 metres (50 feet). Therefore, it has been assumed that these carbonate beds represent time stratigraphic horizons. An isopach

14-29-69-19 W5M



IRETON MARKER BEDS

map of the interval from these beds down to the base of the Gilwood reveals the paleotopgraphy which may have influenced the Gilwood deposition. This procedure, obviously, works only where there are no major unconformities present in the isopach interval and where no differential subsidence has taken place. No unconformity is as yet apparent in the Athabasca River area. Douglas et al (1970) report a disconformity at the top of the Slave Point Formation over most of the Southern Interior Plains, but Jansa and Fischbuch (1974), have made no mention of this hiatus in their study of the upper Middle and lower Upper Devonian carbonate sequence. The Athabasca River area subsided as one unit, as can be noticed in the areal distribution of fringing reefs around the Peace River Arch and along the West Alberta Ridge. As is noted on pages 14 and following, the younger the reefs, the closer they are positioned to the crests of these positive areas.

B. Trend Analysis

Independently of the reconstruction of the paleotopgraphy, the three dimensional configuration of the Gilwood sandstone has been defined, using a trend analysis of the isolith of the Gilwood Member of the Watt Mountain Formation. A trend analysis separates broadscale variations (trends) from the local variations. A trend is derived by the least squares method. This has been defined as $\sum_{n=1}^{n}(Z\ obs_n - Z\ trend_n)^2/_{m-1}$ = minimal. The least squares method is illustrated in Fig. 3. Line T represents the trend in the values. The line has been fitted so that the sum of the squared deviations (d) of Y with respect to X is minimal. The method can also be applied to curved lines, planes and hyperplanes (Harbaugh and Merriam, 1968). In its simplest form, (first degree, fig. 3) the two dimensional profile shows a straight line. The three dimensional diagram shows a plane. The second degree trend is sefined as a parabola or paraboloid. The third degree is harmonic. The first degree trend could thus represent a flat plane, the second degree either a concave or convex plane, the third degree a convex and concave plane (Fig. 3). Because of their relative simplicity, the lower (third or fourth) degree trend surfaces are the most useful. Positive residuals are those values for which Zobs -ZTrend is positive, while for negative residuals Zobs - ZTrend is negative. (Appendix 4 explains the trend surface of isopachs etc. in a little more detail). The above procedure is usually applied by computer. The examples shown in Fig. 3 are also valid for isopachs.

The X and Y coordinates of a sample location are the X and Y axis values, while the sand isolith values are used as the Z axis value. A trend surface represents the regional value (Z) in any location (X,Y), while a local deviation from this trend surface is a local phenomenon. Consequently a trend analysis may separate the regional from the local aspects.

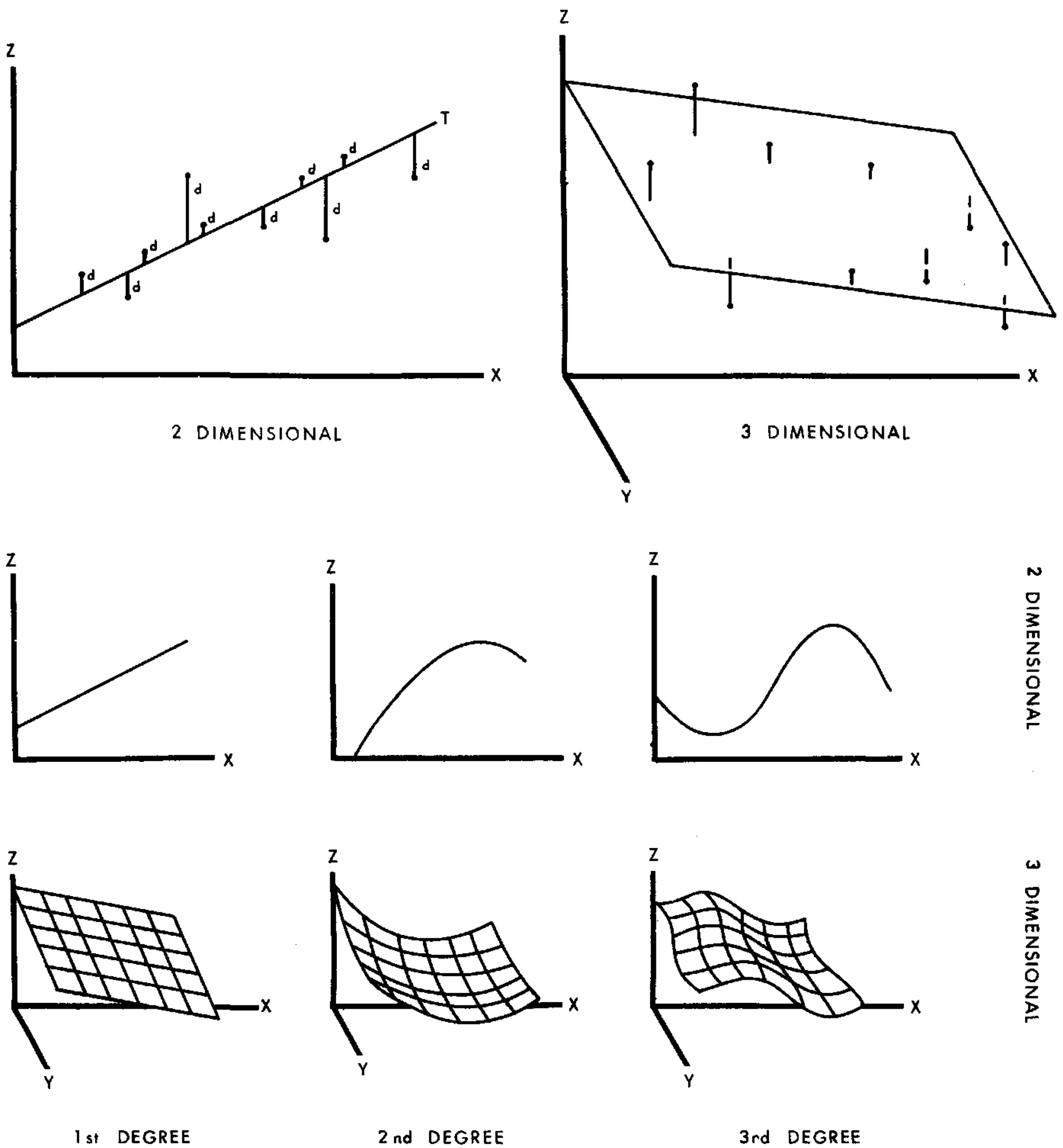
Wermund and Jenkins (1970) have fitted trend surfaces to sandstone percentage values in the Midland Basin, Texas. They conclude that the third or fourth degree trend-surfaces and the resulting positive residuals depict the configuration of the deposits and allows the interpretation of the environment of deposition.

In this study the sandstone isolity values of the 20 m. (60 foot) thick Watt Mountain Formation have been computed (Map 3).

C. Well Log Interpretation

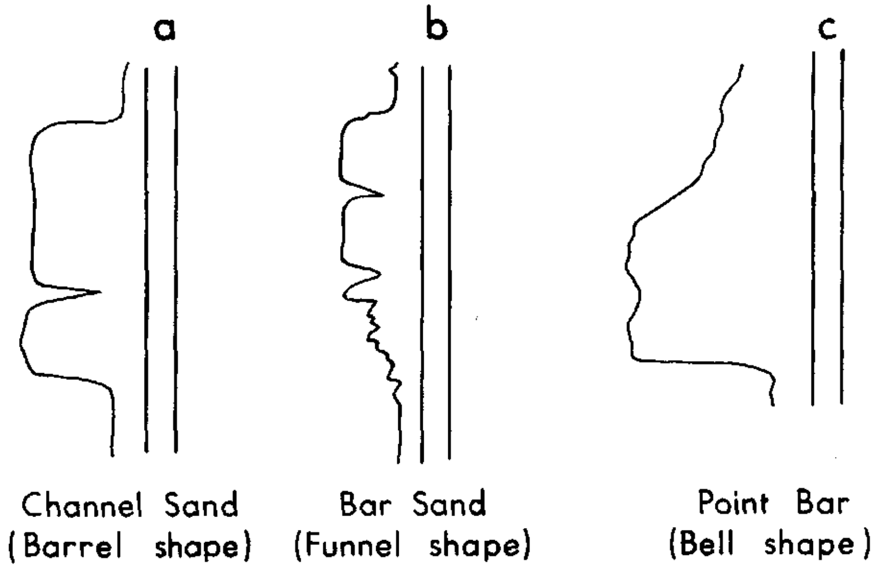
The variations of the spontaneous potential (S.P.) in a borehole are due to variations in the electric potential in the mud column associated with currents flowing through a permeable bed, the adjacent shale beds and the mud column, (Schlumberger, 1972). The S.P. had also been used as an indicator of grainsize variations in sands. A coarse grained assemblage, due to a more agitated environment, has a higher porosity and permeability than a fine-grained assemblage. Geophysical theory predicts that a S.P. curve will move further outwards in the coarser, more porous zone. Pirson (1970) describes how a S.P. curve can be used to interpret changes in grainsize. A complete classiciation of S.P. curves has been proposed and Pirson (1970) claims to be able to distinguish between half a dozen environments. For example a regressive marine sand, as encountered in a prograding delta front, gives rise to a sequence that starts with shale, overlain by silt, fine sand, which becomes coarser to the top. The S.P. responses of a prograding delta could thus be recognized from a "funnel" shaped curve (Fig. 4b). A "fining upwards" cycle as in a point bar of a meandering river, gives rise to a "bell" shaped curve (Fig. 4c). Channel sand deposits, both marine and fluvial, display the

Figure 3



(AFTER HARBAUGH AND MERRIAM, 1968)

TREND SURFACES



a and b after Pirson, 1970
c after Bernard et al, 1970

S.P. CURVES

"box" or "barrel" shape (Fig. 4a). Channel deposits display a more or less uniform grainsize during the lifespan of the channel. The upper and lower contacts of a channel deposit are marked by abrupt change in grainsize. Saitta and Visher (1968) have also presented descriptive interpretations of the S.P. responses. The S.P. method has so far yielded the best results in thick clastic sequences.

D. Core Study

Cores of sixty wells, randomly distributed throughout the area, have been studied in detail for grainsize, rounding, sorting, mineralogical composition and sedimentary structures. Wells east of a line, running from Twp. 75, Rge. 8 W5M to Twp. 55, Rge. 1 W5M have been excluded in this part of the study, since Kramers and Lerbekmo (1967) have already covered this area down to Twp. 63. South of Twp. 63, no Gilwood was desposited. Some 200 hand specimens have been collected and approximately 75 thin sections have been used for mineralogical determination. X-ray diffraction analysis have been obtained from the fraction smaller than 2μm of 45 samples. A classification developed by Pettijohn (unpublished chart, 1944; see Krumbein and Sloss, 1963) has been used to describe the X-ray samples.

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Prof. Dr. P. Hartman (Leiden University) has executed the X-ray diffraction analysis and the determination of clay minerals.

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Dr. J. E. Webb and Phillips Petroleum Company have given permission to use photographs displayed in Plates 1 through 5.

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Dr. H. Ryckborst critically read the thesis, and this thesis would never have been finished without his continually shown interest. And last but not least, many thanks are due to Mrs. N. A. Smit-Verhoorn for her continuous help and encouragement.

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STRATIGRAPHY

A. Lithostratigraphical Abstracts of the Upper Cambrian to Upper Devonian Formations

The stratigraphic definitions of formations used in this study and mentioned in Table I have been compiled for reference purposes.

1. CAMBRIAN

Pika Formation (Middle Cambrian)

The name Pika Formation has first been used by Deiss (1939) for a 165 m. thick sequence of thin bedded, light to dark grey colored limestone and dolomite beds. The type section is situated on Mt. Eisenhower in Banff National Park, Canadian Rocky Mountains. Pugh (1973) has subdivided the Pika Formation into two units, a lower shale, and an upper carbonate unit.

Sullivan Formation (Upper Cambrian)

Walcott (1920) has named a sequence of thin bedded, semicrystalline limestones the Sullivan Formation. The type section is encountered beneath the Sullivan Peak in Banff National Park, Canadian Rocky Mountains. The Sullivan Formation in the area of the present study consists of coarse grained, dolomitic, glauconitic siltstone (Pugh, 1973).

Upper Lynx (Upper Cambrian)

Pugh (1973) refers to the Upper Cambrian Beds penetrated in the Calstan Gulf Kaybob 5-35 (5-35-62-18 W5M) well as the "Upper Lynx". It consists of pink to pale buff, silty, glauconitic, micro - to fine crystalline dolomite which becomes interbedded with dolomitic and micaceous siltstone. Pugh uses the name "Upper Lynx" for those beds which can be correlated to the Upper Division of the Lynx Group in the outcrop area. The individual formations of the Upper Division of the Lynx Group are not recognizable east of the Main Ranges of the Rocky Mountains.

2. Devonian

Granite Wash (Middle to Upper Devonian)

This U.S. oil industry term is applied to a Basal Devonian clastic unit in the study area. It is composed of sandstone and shale. The sandstone is generally fairly well sorted to conglomeratic and is commonly arkosic. The shale is green or maroon in colour. The unit is 0 to 200 m. thick and is distributed over great distances to the north, east and south of the Peace River Arch.

The Granite Wash is a transgressive deposit of reworked detritus of igneous, metamorphic and sedimentary rocks of Pre-Cambrian and Cambrian age. It is overlain by Middle to Upper Devonian beds in an onlap relationship progressively toward the Arch (ASPG, 1960, p. 154).

Keg River Formation (Middle Devonian)

Law (1955) has applied the name Keg River Formation to dark brownish grey, micro-to cryptocrystalline dolomites and limestones in the California Standard Steen River 2-22 well (2-22-227-5 W6M). The Keg River Formation is of Givetian age and is conformably overlain by the Muskeg Formation. The thickness ranges from 0 m. in the west to approximately 100 m. in the eastern parts of the study area (ASPG, 1960, p. 189).

Muskeg Formation (Middle Devonian)

The Muskeg Formation has first been named by Law (1955) in the California Standard Steen River 2-22 (2-22-117-4 W6M) well. (Approximately 450 km. N.W. of Lesser Slave Lake) (Fig. 1). It is an evaporite unit consisting of an interbedded series of dense brown crypto-crystalline dolomite, anhydrite and salt.

In the study area, the Muskeg Formation conformably overlies the Keg River Formation (Givetian) in the east and southeast, while towards the west the Muskeg unconformably succeeds the increasingly older, Cambrian formations.

The Watt Mountain Formation unconformably overlies the Muskeg Formation. The thickness of the Muskeg Formation ranges from more than 120 m. in the east to zero in the west, where the post-Muskeg unconformity truncates this formation. The Muskeg becomes less evaporitic in a westerly direction.

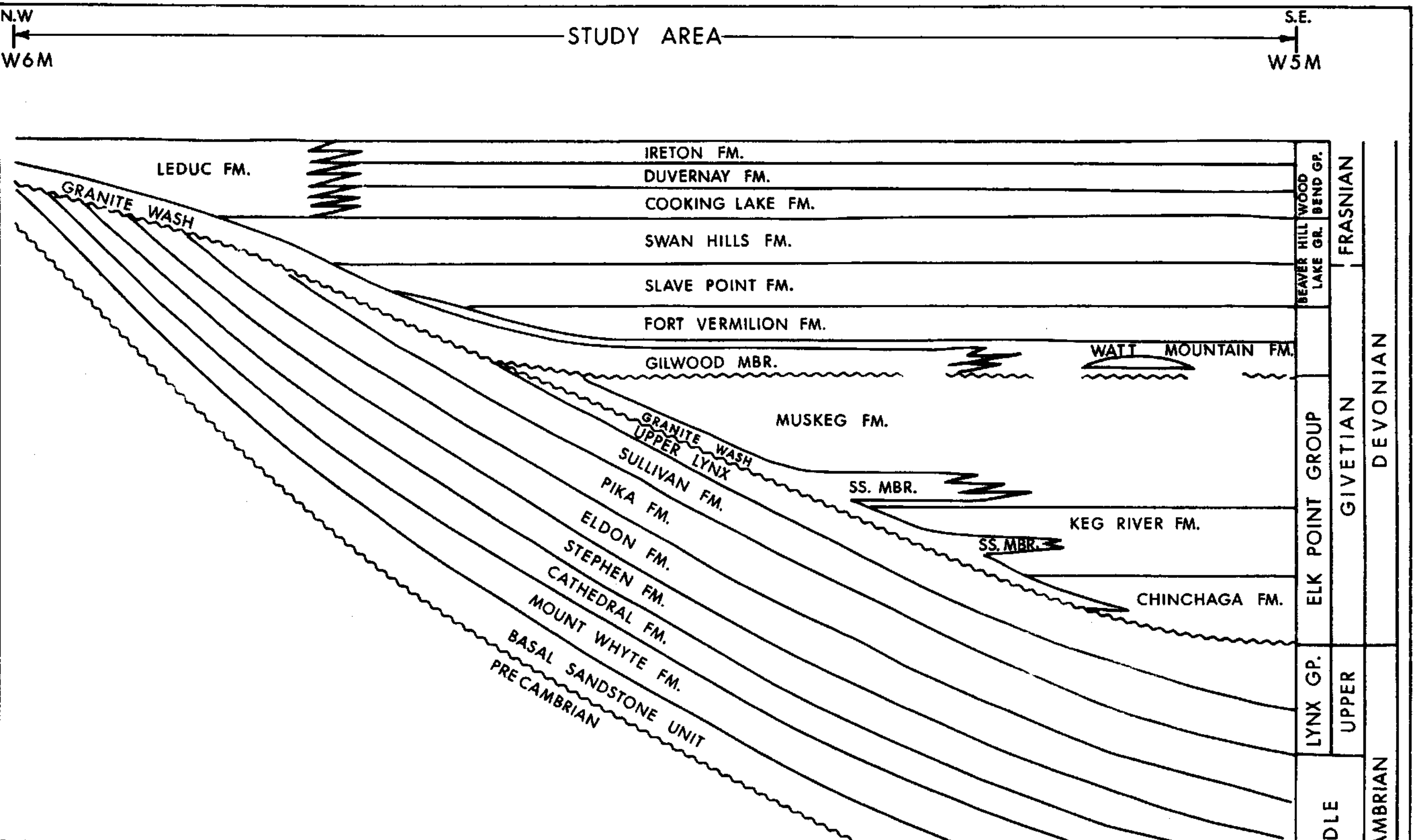


TABLE 1 SCHEMATIC STRATIGRAPHIC CROSS-SECTION AND TABLE OF FORMATIONS

Watt Mountain Formation (Upper Givetian?)

The Watt Mountain formation has also been first defined by Law (1955). It derives its name from a topographic feature, Watt Mountain, at 58° 40' N. and 117° 30' W. The Watt Mountain type section, derived from the California Standard Steen River 2-22 well (2-22-227-5 W6M), is 17 m. thick. The Watt Mountain Formation consists of shale, siltstone, limestone breccia, anhydrite and dolomite. It is recognizable throughout the Elk Point Basin of Alberta and surrounding provinces. Law has correlated the Watt Mountain with the Amco shale of Campbell (1950) and the overlying limestone beds (Great Slave Lake area, N.W.T.). Consequently, the Watt Mountain could be considered equivalent of the lower Slave Point Formation instead of the Upper Elk Point Sub-Group.

In the study area, the Watt Mountain Formation overlies the Middle Devonian Muskeg Formation in the east and progressively older, Cambrian, formations towards the west and north. The Watt Mountain Formation is overlain by the Fort Vermilion formation in most of the study area and by the Swan Hills Formation in locations where the Fort Vermilion Formation has not been developed. Shawa (1969) has questioned the upper Middle Devonian age (Upper Givetian) of the Watt Mountain Formation. He presents arguments for a Lower Frasnian age (p. 395).

Gilwood Member (Upper Givetian?)

The Gilwood Member of the Watt Mountain Formation has been described by Guthrie (1956) in its type section, the Stanolind Giroux Lake #1 well (6-20-65-20 W5M). In this well, it is 10 m. thick, consisting of arkosic to quartzose sandstone, siltstone, and dark green and maroon shale. The Gilwood occurs as an alluvial fan deposit around the Peace River Arch and the West Alberta Ridge (ASPG, 1960). The Gilwood is one of a series of clastic units originating from the Peace River Arch during the Middle Devonian; close to the Arch these clastic sequences coalesce and form the Granite Wash.

The Gilwood Member in the study area varies from an 18 m., often coarse grained to conglomeratic sandstone with abundant pink feldspars and quartz to a sandstone, a few cm. thick, fine grained, argillaceous with very little feldspar.

Fort Vermilion Formation (Upper Givetian?)

Law (1955) has first named the Fort Vermilion Formation as a member of the Middle Devonian Slave Point Formation (p. 1945); later Norris (1963, p. 59) has raised the Fort Vermilion to a formation. The type locality is the Fort Vermilion #1 well (15-32-104-8 W5M). At the type section it consists of 36 m. of brown to white cryptocrystalline anhydrite with some interbeds of dolomite and limestone and minor shale. The contact between the underlying Watt Mountain and the Fort Vermilion Formations appears gradational, while the upper contact with the Slave Point Formation is abrupt.

In the study area, the Fort Vermilion Formation consists also of a shale-carbonate-evaporite sequence, which gradationally overlies the Watt Mountain Formation. The thickness ranges from 0 to approximately 13 m. Close to the Peace River Arch the Fort Vermilion Formation has not been developed.

Slave Point Formation (Middle or Upper Devonian)

The type section of the Slave Point Formation has been described first by Cameron (1922). The type section is located on the north shore of Great Slave Lake, N.W. Territories. The Slave Point Formation consists of brown and gray, fine crystalline, thin bedded, argillaceous, slightly bituminous limestone. The term Slave Point Formation is widely used north of the Peace River Arch, while south of the Arch, the carbonate sequence overlying the Fort Vermilion (or Watt Mountain) Formation is defined as the Swan Hills Formation.

Swan Hills Formation (Upper? Devonian)

The reefal carbonates south of the Peace River Arch have been defined by Fong (1959) as the Swan Hills Member of the Beaverhill Lake Formation. The Swan Hills has subsequently been raised to formation status by Leavitt and Fischbuch (1968, p. 294). Prior to the discovery of oil in the Swan Hills Formation, the name Slave Point Formation was used to designate the carbonate unit south of the Peace River Arch. It consists of two informal units: the dark brown unit, and the overlying light brown unit (Fong, 1959). Both contains abundant Amphipora and stromatoporoids, but in the dark brown unit the fossils are contained in a dark brown cryptocrystalline limestone matrix, whereas in the light brown unit the fossils are encountered in a matrix composed of clastic limestone (ASPG, 1960, p. 339). Jansa and Fischbuch (1974) have correlated the lower part of the Swan Hills Formation, (Fong 1959) consisting of a dark brown unit and the lower part of a light brown unit, with the Slave Point Formation.

The Swan Hills Formation is present in all of the study area, and consists of platform and reefal carbonates or their basinal equivalents.

B. Stratigraphical Framework of the Gilwood Member

The pre-Givetian uplift of the Peace River Arch and the West Alberta Ridge, resulted in an erosional surface. This erosion surface cuts deeper into the underlying formations as a direct function of distance to the Arch and Ridge. The surface is indicated on Table I which portrays a generalized stratigraphic cross-section through the area from northwest to southeast. The Muskeg Formation thins westwards and the sub-Watt Mountain erosional surface merges with the pre-Devonian erosional surface at the Muskeg erosional edge. Increasingly older Cambrian formations sub-crop north and west of the Muskeg erosional limit (Pugh, 1973). As some Cambrian formations consists of sandstone, e.g. the Eldon formation and the Basal Sandstone, it is occasionally difficult or even impossible to distinguish the Gilwood from the Cambrian sandstones. The western and northern edge of the Gilwood is therefore as yet not completely delineated. Pugh (1973) claims that most of the Peace River Arch has been covered with Gilwood Sandstone, which has later been eroded. This claim is not substantiated in his paper. The present author noticed, that in areas north and northeast of the Peace River Arch especially, the basasl sandstone-shale unit covering the Arch could be correlated with the Slave Point Formation or younger rocks. Pugh also states that a sandstone facies of Keg River age is present south of the Arch, more particularly in the High Prairie area (Twp. 72-77, Rge. 14 W5M - 10 W6M). The present study (see Map I) indicates an onlap occurring at the base of the Muskeg. Consequently it may not be likely to find extensive areas covered with Keg River sands beyond the Muskeg erosional edge, although small pockets are a possibility. Map I shows the pre-Watt Mountain subcrop map on which the zero-edge of the Keg River Formation has been indicated.

The Watt Mountain Formation is generally conformably overlain by the Fort Vermilion Formation (Table I). The contact is gradational and no indications of re-working have been noticed in any of the cores examined. Among the few fossils found in the Watt Mountain interval, the majority have come from the top of the formation. The fossils (e.g. Charophyta, Croft 1952, Peck 1953) are indicative of a fresh water environment. It appears that no great subsidense has taken place after the deposition of the Gilwood Sandstone. The Fort Vermilion Formation resembles, to some extent, the present day sabkha deposits of the Persian Gulf. Jansa and Fischbuch (1974) have interpreted different environmental belts in the Fort Vermilion Formation ranging from sub-aerial in the west through an intertidal zone into a logoonal environment in the east. Such belts occur in present day Sabkha region.

A relatively sharp contact separates the Swan Hills Formation from the underlying Fort Vermilion Formation. The Swan Hills Formation has been described by Fischbuch (1968) and Jansa and Fischbuch (1974). It is well known for its reefal build-ups from which half a milliard barrels of oil and large quantities of natural gas have been produced.

SUBSURFACE – GEOLOGICAL ANALYSIS

I. MAPPING PROCEDURES

A. Paleotopography (Map 2)

The paleotopography of the study area has been reconstructed using an isopach interval extending from a younger marker bed in the Ireton Formation to the older pre-Watt Mountain surface. The "red" Ireton marker (Figure 2) was selected for the area north of Twp. 59. Another, the "pink" marker, had to be used for the southern part of the study area, because the "red" marker could not always be picked accurately. The "pink" marker, however, is easily recognized in the south, while north of Twp. 59 it becomes less obvious. Map 2 has been interpreted in the same manner as one interprets a bathymetric map: if the top of the isopach interval is considered to be a horizontal plane, then any changes in the isopach values would be due to the relief of the lower boundary. This interpretation leads to the conclusion that the paleotopography of the Pre-Watt Mountain surface, as depicted on Map 2, comprises a series of ridges radiating from the Peace River Arch and the West Alberta Ridge.

The existence of most of these ridges coincide with the locations of well known reef-controlled oil and gas fields inthe Swan Hills Formation. Even Leduc reefs appear to be located on the slopes and crests of the most prominent of these ridges, e.g. the Sturgeon Lake and Simonette fields (Twp. 71, Rge. 23 W5M and Twp. 63, Rge. 26 W5M respectively).

Fault bounded, graben-like valleys are thought to exist between the ridges in the southwestern part of the map area. The existence of these faults cannot be verified. In the area of the recenly drilled Fina et al Erith well (6-13-49-19 W5M), a northeast-southwest trending barrier has been interpreted in the Swan Hills reservoir. In this case two adjacent wells, producing from the same horizon and displaying different reservoir pressures have been encountered. A discontinuity in the reservoir is assumed to explain this phenomenon. The southwest-northeast direction is also known to exist in shearfaults in the pre-Cambrian underlying the Western Canada Basin in the Zama and Rainbow Lakes area of Northern Alberta. (Hoffman, 1969; Fraser et al, 1972; DeWit et al, 1973). A prominent feature such as the Meadow Lake escarpment in the lower part of the Middle Devonian Lower Elk Point Sub-Group, displays a southwest-northeast direction (Basset and Stout, 1967 and Graystone, Sherwin and Allan, 1964). Thus northeast-southwest alignments appear evident in some major areas throughout the Devonian in the Western Canada Basin.

Another argument for the existence of ridges in the Pre-Watt Mountain surface has been encountered in the fence diagram of the pre-Watt Mountain subcrop (Map I). East of the Kaybob-Fox Creek gas and oil fields (Twp. 61-64, Rge. 18-21 W5M), the erosional edge of the Muskeg Formation displays a bulge towards the east. This bulge coincides with the Simonette-Kaybob Ridge. More to the east, the zero edge of the underlying Keg River Formation displays a similar bulge, indicating that even during the deposition of the Keg River Formation this bulge was a structurally positive area with respect to its immediate surroundings.

There may not be a connection between the ridges and the erosional edges of the sandstone and carbonate layers of the Muskeg Formation. The data (Map 1) show that most of the ridges run uninterrupted from the area where the Muskeg has been eroded into the region where almost the maximum thickness has been preserved. The possibility exists that cuestas formed by the erosional edges of the Muskeg sandstone and carbonate beds, occur more or less parallel to the Muskeg erosional edge. The Muskeg depositional edge, partly obliterated by the late Givetian erosion, has been controlled by the Peace River Arch and the West Alberta Ridge. The depositional edge was probably parallel to the erosional edge.

A thick trend has been detected in the northeast corner of the map area. Its extension towards the east is as yet unknown. Eastward extension through reconstruction of the paleotopography is not yet possible because of the discontinuity of the chosen marker beds, associated with discontinuous carbonate development in the Ireton and Grosmont Formations (Belyea, 1964; Campbell and Oliver, 1968).

Influence of Compaction

1. Synsedimentary Compaction

The deposition of the Gilwood Sandstone in the low areas of Map 2 caused the synsedimentary (and its higher density) exerted a greater pressure in these areas than the thinner clay and silt cover of the more positive areas. The underlying formation subjected to the compaction were the Muskeg and Keg River Formations of Middle Devonian age and the Cambrian Lynx Group and older strata.

The Cambrian beds have been buried and consequently subjected to compaction for approximately 150 million years, prior to the deposition of the Watt Mountain Formation and its Gilwood Member. The Ordovician, Silurian and Lower Devonian are missing in the Athabasca River area, because of the pre-Middle Devonian unconformity. In the Rocky Mountains to the west and in the Williston Basin to the southeast, an aggregate of over 1500 m. of rocks of these ages can still be encountered. Pugh (1970 and 1972), in his studies of the Cambrian Formations, does not indicate the existence of any of the positive features, which were dominant in the Middle Devonian (e.g. West Alberta Ridge, Peace River Arch). Douglas et al (1970) indicate that the West Alberta Ridge became positive during the Lower Devonian. Ordovician, Silurian and possibly Lower Devonian strata would have covered the Cambrian and they were removed prior to the Middle Devonian. The Middle Devonian Chinchaga, Keg River and Muskeg Formations onlap onto the new positive features (i.e. West Alberta Ridge, Peace River Arch; see Map 2). The compactability of the Cambrian strata, which presumably had been buried that deep, would be neglegible.

The main Gilwood Delta is projected to have grown in the area where the Muskeg Formation rests directly on the Granite Wash and/or older (Cambrian) Formations. The thickness of the Muskeg in this area ranges from 80 m. to nil. If synsedimentary compaction had a considerable influence, this should be visible on Map 2. The ridges of Map 2 should be most pronounced there where the Muskeg Formation is the thickest: i.e. the area of the projected seaward edge of the main delta (T60, R18 W5M to T69, R15 W5M). Map 2 shows that this is not the case. To the contrary, the ridges are the most pronounced where the Muskeg Formation is very thin or non-existent. This leads to the conclusion of a structural origin of the main features and their subordinate elements: i.e. the ridges of Map 2.

2. **Post Depositional Compaction**

A certain amount of masking of the pre-Watt Mountain topography is expected as the isopach interval, from which the paleotopography map is derived, is in excess of 300 m., much of it consisting of shales and silts. The amount of compaction in the study area is not known. MacKenzie (1969) showed an estimated total compaction of 14% and 38% respectively in time-equivalent rocks in Jasper National Park, close to the southwest corner of the study area. The rocks studied by MacKenzie consist of shales and silts with some minor carbonates. These rocks resemble the Ireton Formation in which lithologic markers have been selected more to the east. The first value of 14% has been obtained by MacKenzie from a section which occurs in the proximity of a carbonate complex, which contains more calcarous "reef margin" type sediments than the section from which the value of 38% was derived. (MacKenzie, p. 38).

Figure 5A shows the changes that may occur due to compaction. A hypothetical structure (line "3") on the pre-Watt Mountain surface is overlain by a sequence of sedimentary rocks. At the end of time interval "A", an Ireton marker bed is deposited horizontally, shown here as line "1". After burial, a compaction of 40% is assumed to take place. This compaction deforms the marker bed to a curved line "2". This masking of the underlying "hump" is called "drape" as it diminishes the expression of that feature. For the interpretation of the paleotopography (Map 2), the Ireton marker bed is assumed to be horizontal. In Figure 5B a marker bed (2, Figure 5A) has been straightened and the figure shows that the structural high on the reconstructed pre-Watt Mountain surface (3') becomes less pronounced than the original hypothetical surface (line 3, Figure 5A). Figure 5C represents section A-B on Map 2. Once more the Ireton marker bed is shown as a horizontal plain, while the line A'-B' is the pre-Watt Mountain surface as derived from the present isopach values. A"-B" represents the reconstructed pre-Watt Mountain surface, assuming 20% compaction with respect to A'B' and A' "-B' " the same horizon assuming 40% compaction. It is thus plausible that the ridges, shown on Map 2, were more pronounced at the time of Watt Mountain deposition.

The isopach interval used to prepare Map 2, is in excess of 300 m. (1,000 feet) thick, composed of shales and silts. Therefore the paleotopography is expected to have been more pronounced that indicated on Map 2.

B. Trend Surface Analysis

1. **Trend Surface Map**

A trend analysis was used to determine the spatial configuration of the Gilwood Member. The third order trend surface and the positive residuals were computed (Map 3) for that purpose.

The trend surface has been marked by the heavy solid line, indicating a depocenter in the Sturgeon Lake-Snipe Lake area (Map 3). The positive residuals indicate locations which received more than average sand deposition for the area, e.g. channels, bars. These positive residuals are contoured and the result is also shown on Map 3.

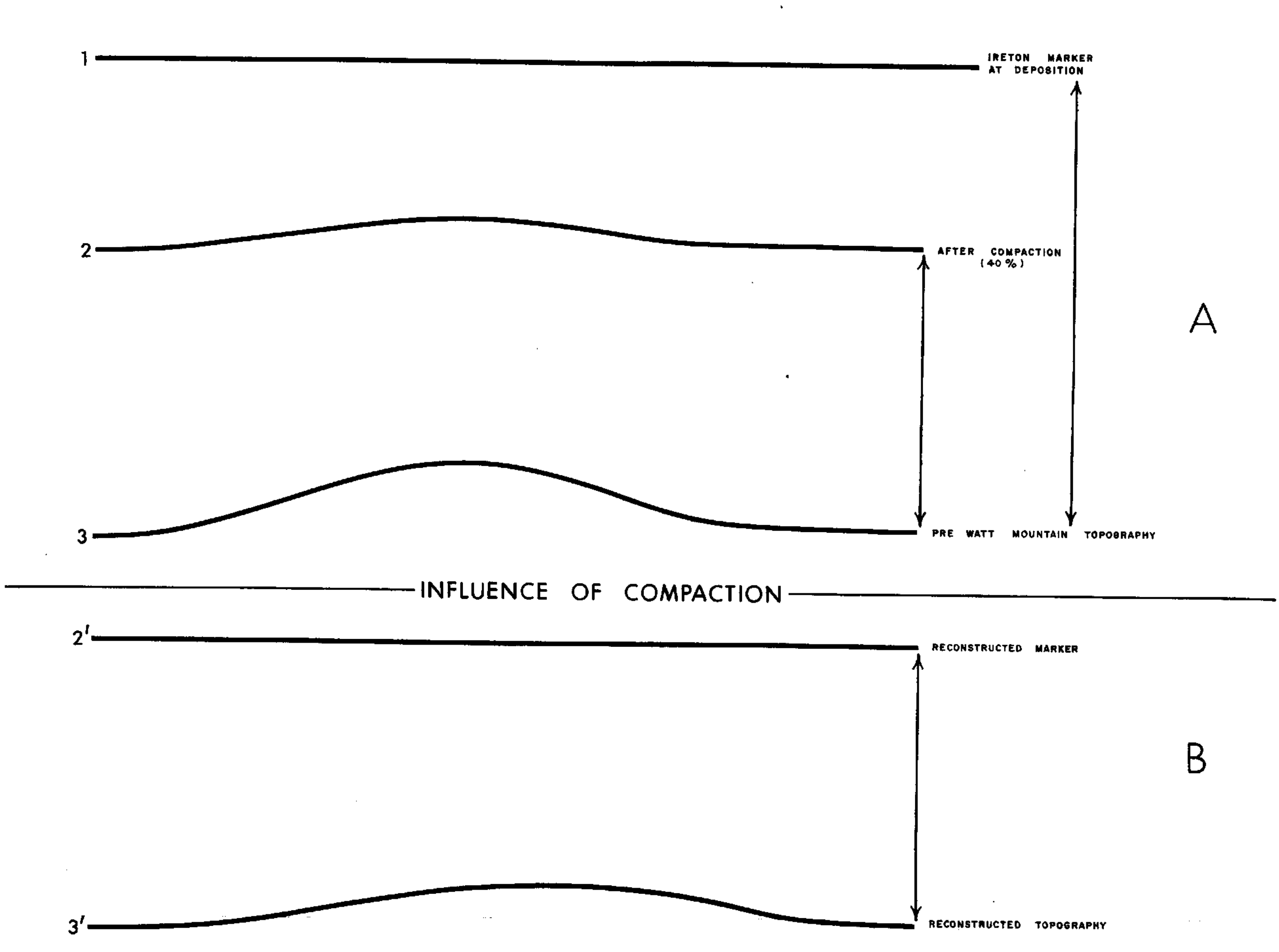
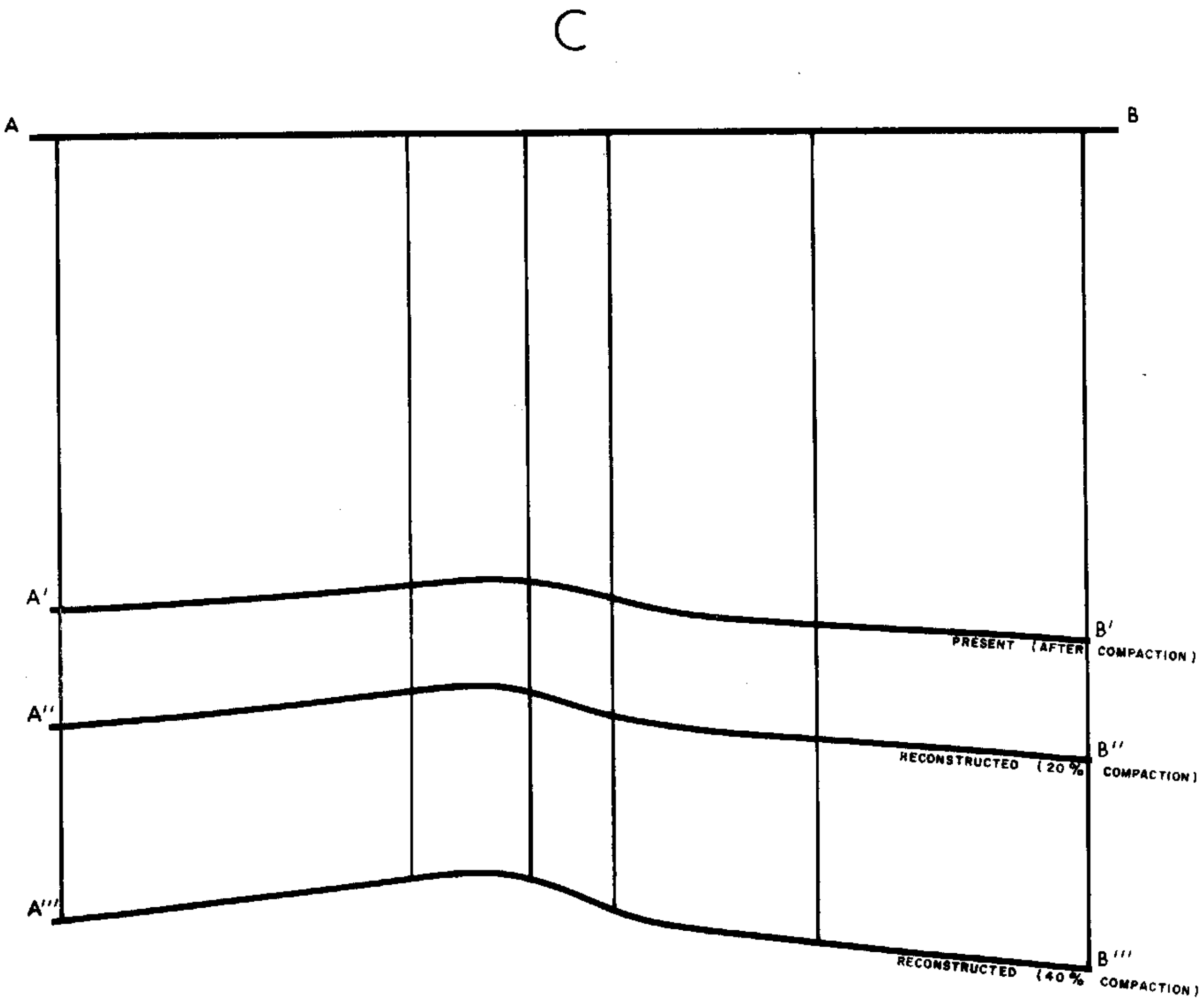

1
IRETON MARKER AT DEPOSITION
2
AFTER COMPACTION (40 %)
A
3
PRE WATT MOUNTAIN TOPOGRAPHY
INFLUENCE OF COMPACTION
2'
RECONSTRUCTED MARKER
B
3'
RECONSTRUCTED TOPOGRAPHY

Figure 5

Figure 5



INFLUENCE OF COMPACTION

In the area north of Twp. 63, several thick, elongated sand bodies are entering from the northwest. These sand bodies have been interpreted as stream channels. Their configuration may indicate a deltaic deposit of the "birdfoot type". Basin-wards the channel environment appears to change to a sand bar environment. A lack of sandstone is apparent over the Swan Hills Ridge. This feature could have blocked off the movement of sediments.

The highest trend surface values occur in the area where the steep slopes of the Peace River Arch and the West Alberta Ridge merge with the almost flat basin bottom topography. Map 3 shows that a nose of high trend surface values extends towards the south along the postulated eastern edge of the West Alberta Ridge. A similar trend is visible north and east of Lesser Slave Lake; this indicates the occurrence of more sand in the area. The Mitsue oilfield (Twp. 69-74, Rge. 3-6 W5M) which produces oil and gas from the Gilwood Sandstone Member is located here and the Gilwood Member is locally more than 10 m. thick. The Gilwood Sandstone distribution diminishes drastically south of Twp. 60. North of Twp. 60 sand bodies occur over the entire width of the study area. In contrast south of Twp. 60 only a relatively narrow ribbon of positive residuals exists. This ribbon displays a N.W.-S.E. direction. The trend surface, representing regional values, becomes lower in a southerly direction. This indicates that the thickness of sandstone, in general, is smaller.

The ribbon consists primarily of three thick sand bodies projecting in a northeasterly direction. Two sand bodies occupy fault-bounded (?) valleys the Stolberg Valley and the Edson Valley respectively (Map 2 and P. 14). A plume of sand is associated with these sand bodies. Both sand bodies have the shape of a sand bar: parallel to the paleotopography. This is in contrast with the deposits north of Twp. 60. The third sand body (Twp. 57-59; Rge. 17-24) is aligned normal to the topography.

Directly north of this last one a thick sand body juts into the basin. When the paleotopography map (Map 2) is overlain by the Gilwood isolith map, it became clear that this sand body covers the Simonette-Kaybob Ridge, probably as a bar deposit.

2. **Isolith Map**

The Isolith Map (Map 4) represents a refined edition of the trend surface map (Map 3). The highest isolith, and trend surface surface values occur in an egg shaped area bounded by the Sturgeon and Snipe Lakes and the region around Twp. 62, Rge. 20 W5M. This egg-shaped area functioned as the depocenter of Gilwood sedimentation south of the Peace River Arch. It also acted as such during the Upper Cambrian (Pugh, 1973, and personal communication). The relatively low isolith values may indicate that the amount of detritus delivered to this part of the study area was not great. The interpretation derived from the trend analysis (Map 3) suggests a "birdfoot-type" delta north of Twp. 63. A birdfoot-type delta implies that the influx of sediment is in excess of what current and wave action can transport (Fisher and Brown, 1969). The birdfoot shapes in the Gilwood sediments and the thickness of the sandstone suggest a quiet, lagoonal (?) depositional environment.

Some areas of no or very little sand, in between the major channels and sand bars, occur in Twp. 71, 72; Rge. 22, 23; and Twp. 65, 66; Rge. 13, 14 and 15. Areas between bars and channels with little or no sand deposition are normal in a deltaic depositional pattern. Such interdistributary areas appear as the locations for flood plains, marshes and swamps. A crevasse splay occurs in Twp. 65, Rge. 22 W5M. A crevasse splay is defined as the product of a temporarily breached levee of one of the stream channels; a crevasse splay is a minature delta, which occurs in the interdistributary areas.

East and south of the Mitsue-Field some sporadic sand developments have been encountered. No sand has as yet been found in the Watt Mountain Formation east of the Fifth Meridian (110° W.).

C. Well Log Interpretation

Map 6 shows that significant differences occur in the spontaneous potential (S.P.) logs from wells in the eastern vs. the western parts of the study area. As explained previously, the S.P. log is a function of the porosity, permeability and grain size. Consequently the S.P. log may indicate fining-upwards and coarsening-upwards cycles, (Prison, 1970). The most prominent feature of S.P. logs from wells in the western areas is a "barrel" or "box" shape, which, in a depositional context, is indicative of channel deposits (e.g. 2-1-67-19 W5M, Map 6). In the east, the more traditional delta and pro-delta coarsening-upwards sequences, are dominant (e.g. 4-4-62-10 W5M). A sharp lower contact in the west merges with a more transitional, serrated contact in the east suggesting a transition to delta margin and marine bar environments (Saitta and Visher, 1968; e.g. 4-15-66-7 W5M, Map 6).

In the northwestern and northern parts of the study area a definite shale break (e.g. Figure 17, 1-2) exists in the sand sequence. It appears that the lower sand unit covers almost the entire area while the upper sand is not present in many places. This applies particularly to the east and south (Fig. 17, 1-2, 5-6).

In some southwestern wells, the S.P. curve is difficult to interpret, since a S.P. log is most useful in thick clastic sequences. The Watt Mountain Formation in this area is wedged between thick carbonate-evaporite successions, and in locations where shales are not well developed either above or below the Gilwood sandstone, the usefulness of the S.P. log becomes doubtful (e.g. 6-11-45-W5M and 1-32-56-19 W5M).

D. Preliminary Conclusion

Certain preliminary observations can be made at this stage. A number of positive areas radiated from the uplands to the west and north, into a more or less flat bottomed basin. These ridges appear to have caused a regulatory influence on the sedimentation in this basin. A deltaic deposit of the "birdfoot type" has occupied most of the area north of Twp. 63. Channel-type deposits of the western and northern portion merged with bars in the south and east. Areas without sand occurred especially in the region of the Swan Hills Ridge. A "birdfoot-type" delta appears to be characteristic of an excess detritus supply with respect to the lesser degree of agitation of the environment of deposition (P. 18). The thickness of Watt Mountain sediments is not great. A protected lagoonal environment in which this delta complex grew, probably existed therefore. The Swan Hills Ridge or the sand deposits of the Mitsue Oilfield farther to the east can have acted as barriers. The Peace River Arch and the West Alberta Ridge have protected the area in the north and west respectively. The Simonette-Kaybob Ridge (Twp. 63, Rge. 20-25 W5M) appears to have exercised a regulating influence on the sedimentation in the area north of Twp. 63, as it closed the area to the south.

The amount of sediment of sand size appears insufficient to cover the entire lagoonal (?) area, as witnessed by the absence of sand in certain locations of the area.

No protective barriers have been distinguished in the eastern part of the area south of Twp. 63 (Maps 3 and 4). There is little evidence of a comparable sedimentation pattern to that north of Twp. 63. The average thickness of the sandstone fraction decreases rapidly in a southern and eastern direction (trendsurface, Map 3). The thicker sand bodies present are located at the mouth of the fault bounded (?) valleys and in embayments (Map 2, 3 and 4; P. 18). The sand was mainly deposited in protected areas. Whatever sand was transported seaward from these small areas may have formed offshore or beach bars parallel to the West Alberta Ridge. It is possible that a northward deflection has occurred associated with long shore currents. The shape of the off-shore (or beach) bars indicate that the longshore currents had a south to north direction. These may have moved the sand towards the Simonette-Kaybob Ridge, but no great concentration of sand is apparent here. Hence, it is possible that less detritus was supplied to the southern portion of the study area than to the northern part of it.

II Core Study

A. X-Ray Analysis and Clay Minerals (Fig. 6 and Appendix 4)[i]

Millot (1970) and Grim (1968) have described the importance of weathering-climate inter-relationships on the formation of different clay minerals. Dunoyer de Segonzac (1970) explained the changes which these minerals may undergo during diagenesis and low grade metamorphism. Weaver (1960) points to the feasability of using clay minerals to differentiate between, on appearance similar, shales.

The petrology of a possible hinterland is of importance in the analysis of some of the clay minerals found in the Watt Mountain Formation. Burwash (1957) examined numerous well samples, both drill cuttings and cores, from the Pre-Cambrian throughout Alberta. Fifty-eight of his samples are derived from wells located on or near the Peace River Arch. According to Burwash (1957) the Arch is composed mainly of granodiorites, schists and gneisses and some quartzites and marbles. Quartz, K-feldspar and plagioclase constitute 75% or more of the rock, with grain sizes ranging from 0.5 to 20 mm.

A study of the fraction smaller than 2μm was undertaken mainly since clay minerals may be used as indicators of the climate of the hinterland and also for the environment of deposition. X-ray diffraction of the samples shows that illite constitutes the prominent clay mineral. Kaolinite, chlorite and a mixed-layer mineral of the illite-chlorite or chlorite-vermiculite type occur in a few samples. Variable amounts of other mixed-layer minerals (illite-montmorillonite) are present in most samples. Other constituents of the fraction smaller than 2-μm are feldspar, quartz and hematite.

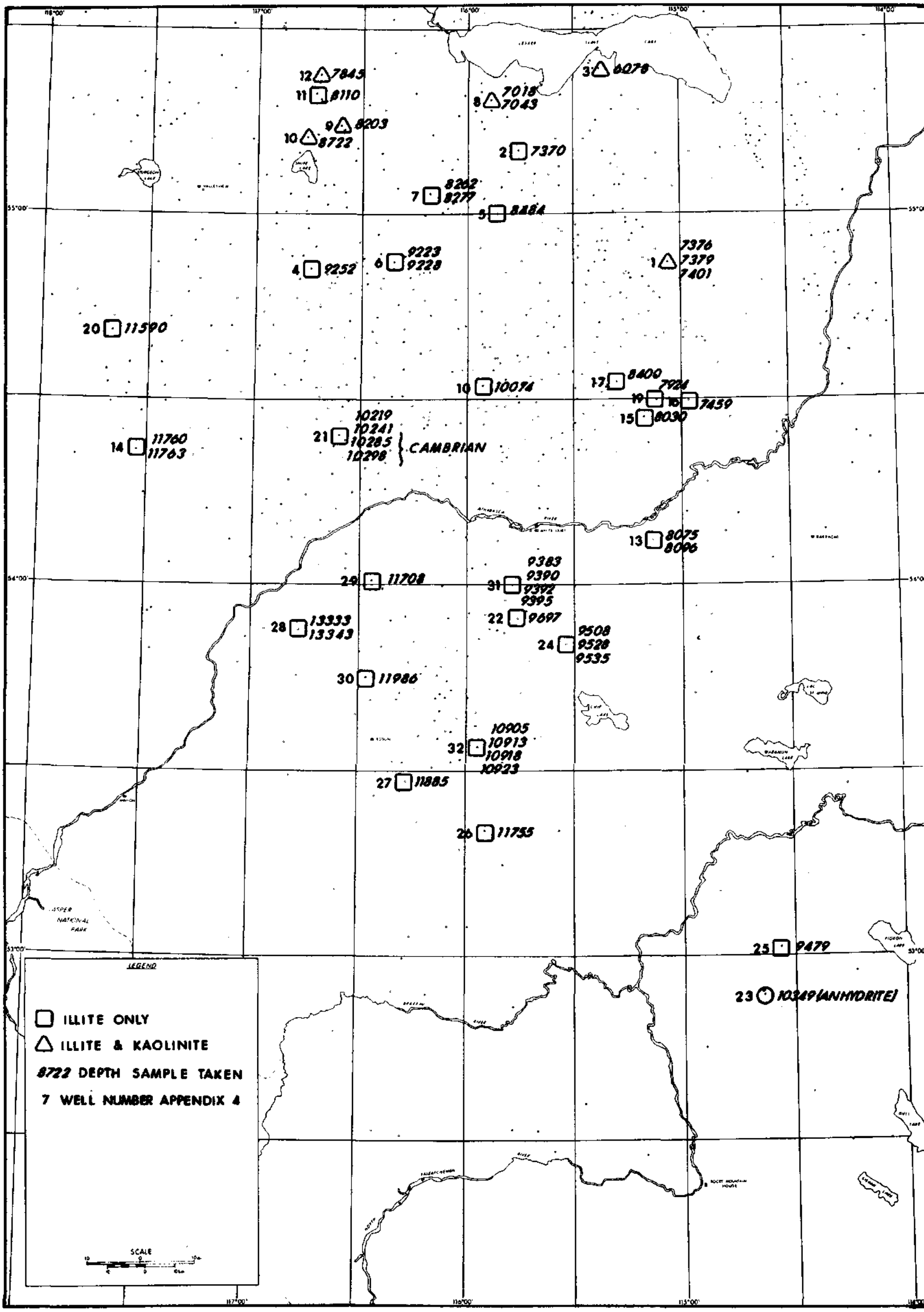
The illite x-ray diffractions are often broad and indicate the presence of small amounts of mixed-layer minerals. A more exact composition of these could not be determined. Most of the mixed-layer minerals are composed of illite-montmorillonite. Some peaks greater than 10 Å (angstrom) remain after heating the sample to 550°C. This indicates possibly an illite-chlorite or a chlorite-vermiculite clay variety. The 060 reflection of the illite is often high, sometimes close to 1.510 Å and this could indicate the presence of celadonite and glauconite.

The kaolinite is poorly crystallized and has the characteristics of a disordered kaolinite. The feldspar is an extremely fine grained microcline.

Figure 7A shows the correlation plots of the clay minerals as a function of depth of burial and formation water salinity. The type of clay minerals are plotted as a function of depth and temperature (Fig. 7B). Formation temperatures have been computed from the bottom hole temperature as indicated on well logs, and the ground temperature at 1 m. depth as reported by Ashton (1969). The diagrams show that no kaolinite is present below a depth of 2700 m. (9000 feet) and above 70°C (160°F) formation temperature. The bottom hole temperatures are customarily those recorded by the logging tools run in the bore hole. It is known that the log temperatures are approximately 28°C (50°F) too low, due to the poor heat conductivity of the drilling mud. More than two years are often needed to reach an equilibrium, as temperature surveys in the Arctic Islands wells did indicate. Dunoyer de Segonzac (1970) and others have shown that kaolinite disappears with increasing depth of burial and with increasing temperatures. Dunoyer de Segonzac also remarks that "seawater at ordinary temperatures stabilizes kaolinite, but above 100C (212°F) illitization occurs" (P. 291).

Kaolinite is also very sensitive to the geochemical environment. It is formed in acidic pore fluids and destroyed in alkaline solutions. In the area under consideration only four formation water analysis are available and one of these (DST #8: 7908'-7939' of the 14-31-63-8 W5M well) could not be used because the water recovery appeared to be too contaminated with drilling mud. The other three water analyses from DST #2, 2-4-74-18 W5M, DST #1, 4-7-74-9 W5M and DST #1, 7-7-57-12 W5M, showed a salinity of 270.000 ppm, 150.000 and 110.000 ppm and a pH of 6.85 and 4.8 respectively. The water salinity of 11 wells on which also x-rays diffraction analyses were carried out, have been calculated using the well logs. Kaolinite is present in

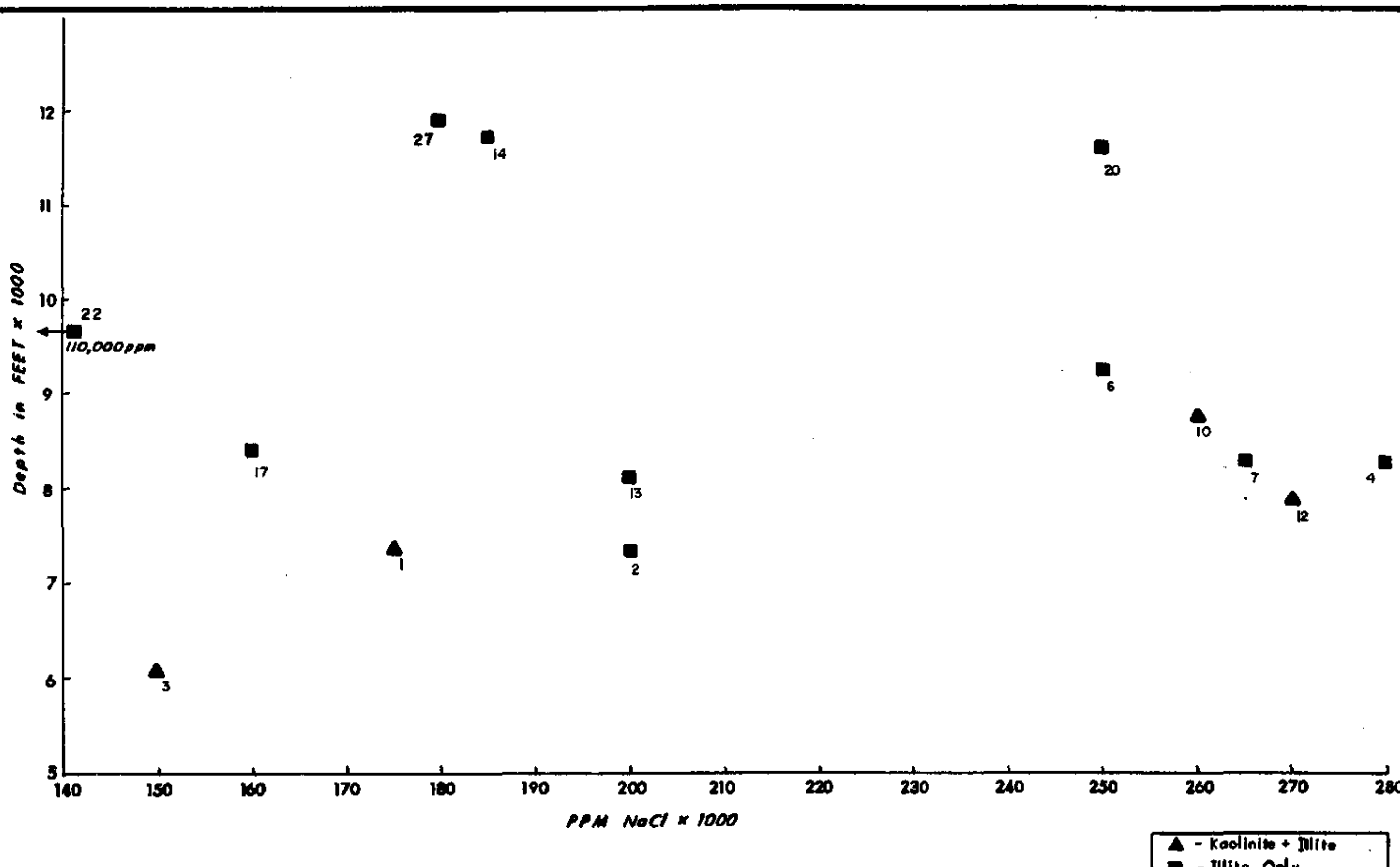
[i]The x-ray diffraction and interpretation were handled by Prof. Dr. P. Hartman and his staff at the Geological Institute of the University of Leyden, the Netherlands.



ATHABASCA RIVER AREA

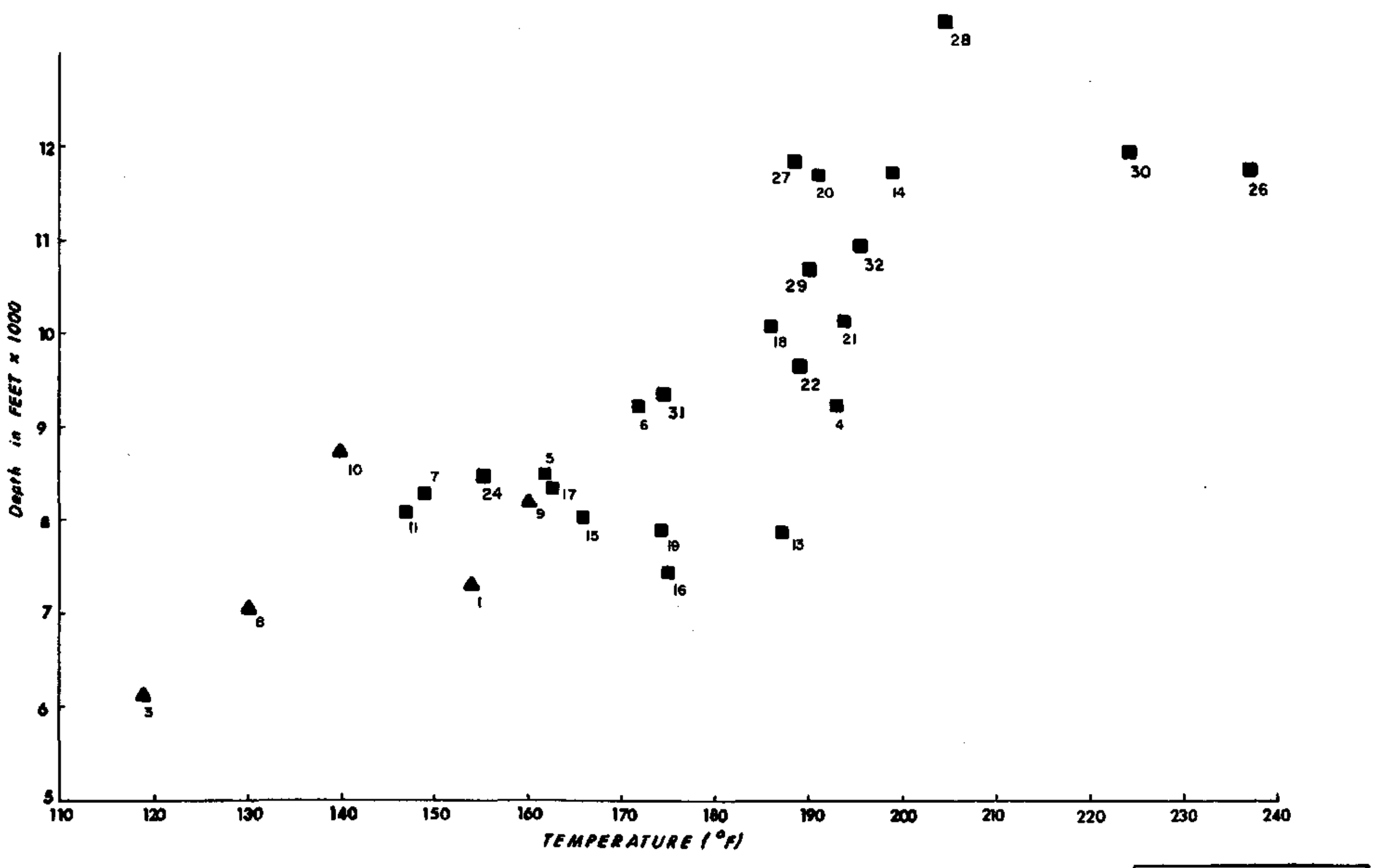
CLAY MINERAL DISTRIBUTION

FIGURE 6



SALINITY - DEPTH PLOT WITH ASSOCIATED CLAY MINERALS

Figure 7A



TEMPERATURE - DEPTH PLOT WITH ASSOCIATED CLAY MINERALS

Figure 7B

four wells (#1, 3, 10 and 12), the others contain illite as the only clay mineral. The salinity of the formation waters ranges from 110.000 ppm NaCl in sample 22 to 280,000 ppm NaCl in sample 4.

Kaolinite is present in the complete range of salinities, but it is absent below 2700 m. (9000 feet).

Jansa and Fischbuch (1974) have also noted the presence of kaolinite in the Gilwood Member. Kramers and Lerbekmo (1967) reported that they did not encounter this clay mineral in the Mitsue-Nipisi area; "the presence of minor amounts of kaolinite, however, remains a possibility" (ibid, p. 364). Also Thachuk (1968, p. 184) writes that in the Nipisi Field: "The composition of the clay infill material falls within the kaolin group". Burwash (1957) mentions the occurrence of kaolinite in pre-Cambrian samples of a few wells, close to the 6th Meridian (118°W) on the Peace River Arch. The Arch is generally overlain by Upper Devonian sediments and so far it has not been proven that the climate of the area had changed significantly between the upermost Middle Devonian and the middle Upper Devonian when the sea covered almost the entire Arch. Kaolinite was probably present in the sediment load of most rivers draining the Arch towards the south and the east.

The presence of the mixed-layer minerals (illite-montmorillonite) could indicate that such minerals were also present in the sediments of at least some streams draining into the sea during the late Givetian-early Frasnian. The illite-montmorillonite mixed-layer phyllosilicate can be formed in the weathering zone in many climates (Millot, 1970; Dunoyer de Segonzac, 1970). It also occurs as an intermediate stage in the illitization of montmorillonite during progressively deeper burial (Dunoyer de Segonzac, 1970). Chloritization takes place in a Mg-rich environment, while illitization happens in a K-rich environment. Chlorite has been detected in only three samples (#36, 58 and 60) and their location is indicated on fig. 6. These three samples have been taken from wells located along the northern edge of the study area. Many other wells contain mixed-layer minerals of unknown composition and the presence of illite-chlorite or chlorite-vermiculite mixed-layer minerals cannot be excluded. Jansa and Fischbuch (1974) also mention the occurrence of small amounts of chlorite in the Watt Mountain Formation.

B. Thin Sections (Table 2)

Table 2 lists some 44 thin sections studied in detail. Three main quartz types were distinguished: a) polycrystalline aggregates, composed of highly undulose quartz with sutured contacts; b) monocrystalline undulose quartz with an extinction greater than five degrees; c) monocrystalline non-undulose or slightly undulose quartz with an extinction less than five degrees. Three types of feldspar; plagioclase, orthoclase and microcline also were found in the samples. No cholorite and only sparse biotite and muscovite were encountered. No glauconite was found and only a few heavy minerals were seen. Three cement types are prevalent throughout the area: silica, carbonate and anhydrite. Sericite was detected in only three slides.

1. Quartz

Quartz is the major constituent of the Gilwood sandstone, ranging from 26% (#57, 9-17-73-18 W5M) to over 80% of the grains (e.g. #1, 10-34-67-10 W5M) with an average of 64%. Both polycrystalline and highly undulose quartz are more abundant among the larger grain sizes.

a) Polycrystalline Quartz

The thin sections show that the percentage of polycrystalline quartz diminishes in a southerly and southeasterly direction (Map 5). The area has therefore been subdivided into two parts: (a) north of Twp. 60 and (b) south thereof. North of Twp. 60 the percentage of polyquartz is generally 10% or higher; south of Twp. 60 only 1 or 2% of the sample consists of polyquartz. This is perhaps due to either a longer transport distance resulting in a breakdown of polyquartz into single highly undulose quartz grains, or to the availability of polycrystalline quartz from the source area.

The polycrystalline quartz has been subdivided into three constituent groups.

a) Five or less subsequant to moderately elongated crystals;

b) More than five subequant to moderately elongated crystals;

c) Elongated crystals.

It was found that the polycrystalline quartz of group "c" always contain more than five crystals.

Tables 3 lists the percentage of the total polycrystalline quartz content per thin section. A general increase of group "c" is detectable in a west-east direction, while neither of the other two groups shows a specific pattern in their distribution. One or both of groups "a" and "b" are present in variable amounts in all thin sections. Group "a" (polycrystalline quartz) seems to be dominant in almost all samples. Group "c" is associated with a decrease of either "a" or "b".

SAMPLE	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
# 1 10-34-67-10 W5	16 (20)	39 (49)	14 (17)	1 (1)	6 (7)	5 (6)	—	—	—	—	—	4 (0)	—	13 (0)	—	2 (0)	—
# 2 IDEM	10 (16)	16 (26)	13 (20)	1 (2)	16 (26)	6 (10)	—	—	—	—	—	—	7 (0)	25 (0)	6 (0)	—	—
# 6 4-28-68-10 W5	10 (14)	28 (41)	8 (11)	—	7 (10)	17 (24)	—	—	—	—	—	—	—	22 (0)	8 (0)	—	—
# 11 4-7-74-9 W5	3 (4)	22 (31)	17 (25)	6 (8)	11 (15)	10 (14)	2 (3)	—	—	—	—	—	1 (0)	5 (0)	23 (0)	—	—
# 16 4-34-67-18 W5	9 (12)	30 (39)	18 (23)	—	7 (9)	13 (17)	—	—	—	—	—	—	1 (0)	15 (0)	7 (0)	—	—
# 21 10-13-68-16 W5	8 (16)	18 (35)	17 (33)	—	6 (12)	2 (4)	—	—	—	—	—	5 (0)	—	44 (0)	—	—	—
# 22 IDEM	10 (13)	31 (39)	21 (26)	1 (1)	9 (11)	8 (10)	—	—	—	—	—	—	—	15 (0)	5 (0)	—	—
# 25 6-21-69-16 W5	8 (10)	32 (42)	12 (16)	—	15 (19)	9 (12)	—	—	—	—	—	16 (0)	—	4 (0)	3 (0)	—	—
# 43 11-18-72-17 W5	26 (33)	27 (34)	3 (4)	—	9 (11)	14 (18)	—	—	—	—	—	8 (0)	—	7 (0)	1 (0)	—	—
# 47 2-21-73-13 W5	5 (7)	20 (27)	10 (14)	1 (1)	25 (35)	12 (16)	—	—	—	—	—	2 (0)	—	22 (0)	3 (0)	—	—
# 48 IDEM	7 (10)	46 (62)	—	—	2 (3)	18 (25)	—	—	—	—	—	27 (0)	—	—	—	—	—
# 49 IDEM	11 (16)	29 (41)	—	—	19 (27)	11 (16)	—	—	—	—	—	30 (0)	—	—	—	—	—
# 50 IDEM	9 (11)	43 (51)	—	—	19 (22)	13 (15)	1 (1)	—	—	—	—	13 (0)	—	2 (0)	—	—	—
#51A IDEM	8 (11)	26 (36)	12 (16)	—	12 (16)	15 (21)	—	—	—	—	—	27 (0)	—	—	—	—	—
# 52 IDEM	10 (11)	25 (30)	9 (10)	—	24 (28)	16 (18)	2 (2)	—	—	—	—	—	—	12 (0)	—	1	1 (1)
# 53 IDEM	21 (27)	15 (20)	15 (19)	—	16 (21)	9 (12)	1 (1)	—	—	—	—	—	14 (0)	9 (0)	—	—	—
# 55 9-17-73-18 W5	8 (35)	3 (10)	7 (16)	—	7 (29)	3 (9)	—	—	—	—	—	—	—	71 (0)	—	—	1 (1)
# 56 IDEM	11 (13)	17 (20)	7 (8)	—	30 (35)	18 (21)	2 (2)	—	—	—	—	12 (0)	—	1 (0)	—	2	—
# 57 IDEM	8 (9)	1 (1)	14 (16)	1 (1)	51 (58)	12 (14)	—	1 (1)	—	—	—	9 (0)	—	3 (0)	—	—	—
# 58 2-4-74-18 W5	10 (14)	9 (12)	4 (5)	—	34 (46)	16 (22)	1 (1)	—	—	—	—	7 (0)	—	19 (0)	—	—	—
# 59 IDEM	15 (18)	7 (8)	11 (13)	—	39 (47)	12 (14)	—	—	—	—	—	15 (0)	—	1 (0)	—	—	—
# 61 IDEM	36 (43)	3 (4)	12 (14)	—	16 (20)	16 (19)	—	—	—	—	—	17 (0)	—	—	—	—	—
# 63 10-26-59-9 W5	0 (2)	2 (3)	16 (62)	—	12 (30)	1 (2)	—	—	—	—	—	66 (0)	—	2 (0)	—	—	1 (1)
# 70 4-13-63-9 W5	5 (6)	12 (14)	37 (43)	—	31 (36)	1 (1)	—	—	—	—	—	—	7 (0)	7 (0)	—	—	—
# 73 4-18-64-9 W5	17 (20)	5 (6)	29 (35)	1 (1)	28 (34)	3 (4)	—	—	—	—	—	2 (0)	4 (0)	4 (0)	7 (0)	—	—
# 78 14-31-63-8 W5	0 (1)	17 (23)	23 (32)	—	26 (37)	4 (6)	—	1 (1)	—	—	—	2 (0)	7 (0)	20 (0)	—	—	—
# 80 4-15-66-7 W5	10 (12)	18 (22)	23 (27)	2 (2)	22 (26)	9 (11)	—	—	—	—	—	3 (0)	3 (0)	10 (0)	—	—	—
# 81 4-4-62-10 W5	26 (34)	24 (32)	11 (14)	—	10 (13)	5 (7)	—	—	—	—	—	—	19 (0)	5 (0)	—	—	—
# 82 10-5-65-23 W5	29 (35)	19 (23)	13 (15)	—	8 (10)	15 (17)	—	—	—	—	—	—	8 (10)	2 (0)	6 (0)	—	—
# 83 IDEM	24 (26)	18 (19)	14 (15)	—	22 (24)	14 (15)	1 (1)	—	—	—	—	4 (0)	1 (0)	1 (0)	1 (0)	—	—
# 84 IDEM	16 (33)	12 (28)	14 (23)	—	5 (11)	3 (5)	—	—	—	—	—	—	—	30 (0)	—	—	20 (0)
# 85 10-18-64-19 W5	19 (21)	16 (18)	21 (23)	—	25 (27)	10 (10)	—	—	—	—	—	6 (0)	1 (0)	1 (0)	—	—	1 (1)
# 92 5-35-62-18 W5	44 (44)	22 (22)	7 (9)	—	16 (16)	9 (9)	—	—	—	—	—	—	2 (0)	—	—	—	—
# 95 IDEM	26 (30)	21 (24)	19 (22)	—	18 (20)	4 (4)	—	—	—	—	—	1 (0)	4 (0)	6 (0)	1 (0)	—	—
#107 4-13-57-12 W5	0 (1)	29 (56)	9 (10)	—	11 (28)	1 (4)	—	—	—	—	—	10 (0)	—	27 (0)	12 (0)	—	1 (1)
#123 6-11-45-13 W5	1 (1)	37 (48)	13 (18)	—	24 (32)	1 (1)	—	—	—	—	—	—	—	10 (0)	14 (0)	—	—
#127 2-25-50-14 W5	6 (7)	49 (52)	10 (12)	—	22 (27)	2 (2)	—	—	—	—	—	1 (0)	—	5 (0)	11 (0)	—	—
#129 IDEM	5 (6)	49 (57)	10 (12)	—	18 (21)	2 (2)	—	—	—	—	—	12 (0)	—	1 (0)	1 (0)	—	2 (2)
#135 1-32-56-19 W5	10 (10)	43 (44)	14 (15)	—	25 (29)	1 (2)	—	—	—	—	—	1 (0)	—	1 (0)	5 (0)	—	—
#137 IDEM	3 (4)	43 (56)	1 (1)	1 (1)	29 (37)	1 (1)	—	—	—	—	—	1 (0)	—	1 (0)	20 (0)	—	—
#139 6-15-58-17 W5	2 (2)	35 (42)	12 (14)	—	30 (36)	5 (6)	—	—	—	—	—	—	—	2 (0)	14 (0)	—	—
#141 15-29-55-17 W5	1 (1)	47 (47)	22 (23)	—	27 (27)	2 (2)	—	—	—	—	—	—	—	—	1 (0)	—	—
#143 IDEM	9 (10)	45 (45)	16 (16)	—	23 (23)	6 (6)	—	—	—	—	—	—	—	1 (0)	—	—	—
#153 10-12-58-13 W5	1 (1)	39 (53)	4 (8)	0 (3)	16 (27)	2 (4)	—	—	—	—	—	3 (0)	—	32 (0)	—	—	3 (4)

REMARKS

1 —
2 —
6 —
11 —
16 Q. Grains are broken.
21 Congl. framework.
22 Q. Grains fractured.
25 —
43 Oil Stain?
47 —
48 Heavily fract Q. Poly Q. Floating in matrix oil stain
49 Oil stain? Three fining upward cycles.
50 Red Shale. Red Opaque material.
51A —
52 Heavy minerals.
53 —
55 Hematite finely dispersed in places.
56 Sericitized feldspar grains.
57 Red-brown clay matrix often pushed aside by carb.
58 Q. Grains fractured.
59 Microcline sericitized. Poly Q. broken.
61 Q. + Orthocl. grains broken. Orthocl. sercitized.
63 Grains floating in matrix. Bigger crystals orthocl.
70 Q. grains with plag. core. Orthocl. have inclusions.
73 Q. grains broken. Some feldspar also.
78 —
80 Undul. Q. with microcl core. Sil. + Carb. replacement cement
81 Q. grains broken after depos. Feldspar badly altered.
82 Q. fract. Rutile.
83 Feldspar sericitized.
84 Plant fragm. Charophyta? Poly Q. broken.
85 Hematite. Also coating on some grains.
92 —
95 Feldspar broken. Hematite. Cambrian
107 Hematite.
123 Q. grains fractured.
127 —
129 Q. grains broken. Rutile.
135 Dust rings. Microcline badly weathered.
137 Feldspar + Poly Q badly weathered.
139 Poly Q. badly weathered.
141 —
143 Feldspar weathered.
153 Shell fragments

A = Polycrystalline Quartz
B = Single Highly Undulous Quartz
C = Single Non—Undulous Quartz
D = Plagioclase
E = Orthoclase (K — Feldspar)
F = Microcline
G = Muscovite
H = Biotite
I = Chlorite
J = Glauconite
K = Accessories
L = Matrix
M = Silica
N = Carbonate — Cement
O = Evaporite
P = Sericite
Q = Others

Amount shown is percentage of sample
Amount between ( ) is percentage of Grains

Table 2

Mineralogical Composition

SPL.	Q/F	AV.	MQ/PQ	AV.	SQ/uQ	AV.	M/O	AV.	S(<5)	AV.	S(>5)	AV.	L	AV.	LOC.
1	6.1	3.3		0.2		0.9		67		33		0			
		2.8		3.1		0.3		0.5		54		47		0	
2	1.6		2.8		0.4		0.4		40		60		0		1
6	1.9		3.7		0.2		2.4		89		0		11		2
11	1.6		14.0		0.7		0.0		66		34		0		3
16	2.8		5.1		0.4		2.0		67		33		0		4
21	5.2		4.2		0.6		0.3		75		25		0		
		4.2		4.5		0.5		0.6		79		13		10	
22	3.5		4.9		0.5		0.9		83		0		17		5
25	2.2		5.8		0.3		0.6		52		35		13		6
43	2.5		1.2		0.05		1.6		33		67		0		7
47	0.9		6.0		0.4		0.5		50		32		18		
48	2.6		6.2		0		8.0		50		40		10		
49	1.3		2.5		0		0.6		50		40		10		
		1.5		3.5		0.2		0.8		65		28		7	
50	1.7		4.5		0		0.7		83		17		0		8
51A	1.7		4.6		0.3		1.3		77		23		0		
52	1.1		3.6		0.3		0.6		86		14		0		
53	2.0		1.4		0.4		0.6		64		36		0		
55	1.6		0.7		0.4		0.3		66		34		0		
		0.8		1.3		0.4		0.2		89		11		0	
57	0.4		2.0		1.6		0.2		100		0		0		9
56	0.8		2.1		0.3		0.6		100		0		0		
58	0.5		1.2		0.2		0.5		85		0		15		
		0.8		0.7		0.3		0.5		55		34		11	
59	0.6		1.2		0.5		0.3		38		62		0		10
61	1.5		0.4		0.3		1.0		41		40		19		
63	2.0		32.5		12.4		0.06		75		0		25		11
70	1.7		9.5		2.1		0.03		11		22		67		12
73	1.6		2.0		1.3		0.1		39		34		27		13
78	1.3		55.0		1.3		0.2		57		0		43		14
80	1.6		4.0		0.7		0.4		50		0		50		15
81	4.0		1.3		0.2		0.5		50		32		18		16
84	5.2		1.5		0.3		0.4		91		2		7		
82	2.7	2.7	1.1	1.3	0.2	0.3	1.7	0.8	58	60	30	29	12	11	17
83	1.5		1.3		0.3		0.6		33		54		13		
85	1.9		2.0		0.6		0.4		60		40		0		18
92	3.0		0.7		0.1		0.5		84		11		5		19
95	3.1		1.5		0.4		0.2		78		10		12		19C
107	2.0		66.0		0.2		0.1		75		0		25		20
123	2.0	66.0	0.4		0.03		75		25		0		21		
127	2.4	9.0	0.2		0.07		50		50		0				
		2.8		10.2		0.2		0.08		53		44		3	
129	3.3		11.5		0.2		0.08		57		38		5		22
137	1.6		14.0		0.01		0.03		100		0		0		
		1.8		8.3		0.1		0.04		66		23		11	23
135	2.2		5.0		0.3		0.07		33		45		22		
139	1.4		28.0		0.3		0.2		100		0		0		24
141	2.4		70.0		0.4		0.07		80		20		0		
		2.4		12.0		0.3		0.1		90		10		0	25
143	2.4		6.1		0.3		0.2		100		0		0		
153	1.8		61.0		0.1		0.1		56		19		25		26

Kramers and Lerbekmo (1967)

SPL	Q/F	AV.	LOC.
122	2.8		
124	3.7		
125	1.7	2.5	12-7-73-4W5M
131	1.6		
133	1.8		
136	8.0		
179	6.6		
181	3.5		
182	3.1		
183	1.8	3.7	12-3-73-5W5M
184	3.5		
185	7.2		
186	4.5		
294	3.7	4.4	10-28-73-5W5M
210	5.2		
221	5.2		
224	5.2	5.2	10-5-73-5W5M
225	5.2		

Legend

Q/F = Quartz - Feldspar Ratio
MQ/PQ = Monoquartz - Polyquartz Ratio
SQ/uQ = Nonundulatory - Undulatory Quartz Ratio
M/O = Microcline - Orthoclase Ratio
S (<5) = Polycrystalline Quartz, consisting of 5 or less subequant grains
S (>5) = Polycrystalline Quartz, consisting of more than 5 subequant grains
L = Polycrystalline Quartz, consisting of elongated grains

Note: Samples placed in correct depth sequence per location;

eg. #47 is the shallowest and #53 is the deepest samples of location #18

Table 3

Quartz - Feldspar ratios of 44 thinsections (this study)
and
Quartz - Feldspar ratios computed by Kramers and Lerbekmo (1967)

A sandsize polycrystalline quartz grain, which may originate from massive plutonic rocks is normally composed of two to five quartz crystals which are very similar in size and shape; subequant to moderately elongated (Group "a"). Upon disintegration, gneisses and schists yield polycrystalline quartz composed of five or more crystals. Such crystals are often flattened (elongated) and display frequently a bimodal size distribution (Group "c"). The bimodality is a reflection of recrystallization, since the smaller crystals are mostly the newly developed ones. (Blatt, Middleton and Murray 1972). Polycrystalline quartz containing more than five subequant to moderately elongated crystals, can be traced back to either plutonic or metamorphic rocks. In this case, a plutonic origin however is more likely due to the absence of a bimodal crystal size distribution (Group "b").

b) Highly Undulose Quartz

Highly Undulose quartz has experienced high pressures and temperatures. It is found in metamorphic and plutonic rocks (Blatt and Christie, 1963), but it can also be the result of diagenesis, folding and faulting (Conolly, 1965). A third provenance is the decomposition of polycrystalline quartz.

East and southeast from the area with thick sand deposits (Twp. 62-73, Rge. 17-24 W5M), a distinct decrease in polyquartz and an increase in undulose monoquartz is apparent. South of Twp. 60, undulose monoquartz is the major type of quartz found in the sediment.

c) Non-Undulose Quartz

Non-undulose quartz includes undulatory quartz with an extinction of less than five degrees. With the decrease of grainsize, the percentage of non-undulose quartz increases toward the southeast and east. This increase is particularly noticeable in the area east of the Swan Hills oil field (Twp. 63-71; Rge. 8-12 W5M).

Non-undulose quartz does not show the signs of strain as is the case of highly undulose quartz. The primary source for non-undulatory quartz is mostly extrusive igneous rocks. Non-undulatory quartz appears more resistant to mechanical and chemical breakdown than highly undulose quartz. Small grains of highly undulose quartz may appear non-undulose in thin sections. Hence an increase in the percentage of non-undulose quartz could indicate some distance of sand transport and sand reworking; more mature sandstones are associated with a higher percentage of non-undulose quartz.

2. Feldspar

Feldspar is, after quartz, the most common constituent of the Gilwood Sandstone. The amount of feldspar in the Gilwood samples ranges from 8% (#21, 10-13-68-16 W5M) to over 60% (#57, 9-17-73-18 W5M). In general the percentage of feldspar diminishes from west to east.

Orthoclase is by far the most abundant. It is present in all the samples. Microcline is also omnipresent, but its percentage is appreciably lower. Plagioclase was encountered in only ten samples; four samples were collected from wells close to the Peace River Arch and the West Alberta Ridge. (e.g. #47, 2-21-73-13 W5M, #137, 1-32-56-19 W5M), whereas the other six samples are located east of the Swan Hills Ridge. Shawa (1969) and Kramers and Lerbekmo (1967) have observed plagioclase in the Utikuma and the Nipisi - Mitsue areas respectively. Jansa and Fischbuch (1974) do not mention the occurrence of plagioclase in their study.

Feldspars with rounded quartz overgrowth were encountered in three locations east of the Swan Hills Ridge, and in a fourth location just north of the Simonette-Kaybob ridge. Jansa and Fischbuch (1979), Shawa (1969), Thackuk (1968), nor Kramers and Lerbekmo (1967) refer to the occurrence of such feldspars.

Quartz and feldspar grains which indicate weathering conditions have been found in seven wells. Weathering of the grains has been established from sericitization of the feldspars and a cloudy, corroded and fractured appearance of both feldspar and quartz. Fractures of weathered grains were often found to be lined with minuscule, clay-like minerals. Such substances are also found in protected parts of pitted grain surfaces. Six out of seven wells, in which weathered grains were encountered, are located close to the western edge of the study area. Most weathered feldspar grains are orthoclase and microcline. There appears to be no preference for sericitization of orthoclase over microcline.

Shaw (1969) has reported weathered grains in the Utikuma area: Kramers and Lerbekmo (1967) mention weathered feldspar. Jansa and Fischbuch (1974) mention weathered feldspar. Jansa and Fischbuch (1974) note minor weathering of feldspars and no weathering of quartz.

Broken and fractured quartz and feldspar grains were found to occur throughout the area. Plate 6 shows a quartz grain which has been broken after deposition. The components of the grain occur in optial continuity and have moved very little since their breakup. No rounding of the sharp corners of the broken grain has taken place. Other quartz grains show flat sides and one or more, only slightly rounded corners. Sharp edges and corners of quartz grains indicate breakup during transportation shortly before final deposition.

Quartz-Feldspar Ratio

The quartz-feldspar ratios of 44 thin sections (Figure 8A, Table 3) show that quartz is generally more abundant than feldspar. In only two locations in the northwest corner of the area ratios of 0.8 were encountered. There appears to be a general increase of the quartz-feldspar ratio values away from the Peace River Arch and the West Alberta Ridge. To the east of Rge. 10 W5M (Loc. #13, 14, 15, 16), lower values are encountered. An area of maximum quartz-feldspar ratios appears to be situated between Twp. 60 and 73 and Rge. 10 and 18 W5M. A second high was found south of a line from Twp. 55, Rge. 17 W5M to Twp. 59, Rge. 9 W5M. A ribbon of lower ratios was mapped between these two areas. A high ratio was also encountered in one well in the extreme western part of the study area (#18: 10-5-65-23 W5M).

A generally increasing quartz-feldspar ratio is also found in a vertical succession from older to younger deposits. Locality #9 (2-21-73-13 W5M), from which seven samples were examined, indicates a higher ratio at the base and the top than in the middle part of the Gilwood sandstone. The same pattern is found at locality #10 (9-17-73-18 W5M).

Kramers and Lerbekmo (1967) list the mineralogical composition of four samples in the northern part of the Mitsue oil field. Apparently, ratios at the top of the Gilwood are high, while the middle part contains lower quartz-feldspar ratios.

The distribution of the monocrystalline quartz over polycrystalline quartz ratios (Fig. 8B, Table 3) appears to be more random. Areal variation indicates an east and southeastward decreasing trend in the amount of polycrystalline quartz. The ratios in a vertical succession however, do not show significant patterns.

The ratios of non-undulose quartz with an extinction angle less than 5° vs. undulose quartz (both mono- and polycrystalline) (Fig. 8C, Table 3) show generally an increase in non-undulose quartz from west to east.

The distribution of the microcline vs. orthoclase ratio appears random. Some high values occur in the northern and northwestern part of the area (e.g. 1.6 at Loc. 8: 11-18-72-17 W5M). A number of low ratios are noticeable in the eastern and southern part (e.g. 0.03 at Loc. 22: 6-11-45-13 W5M) (Fig. 8D, Table 3).

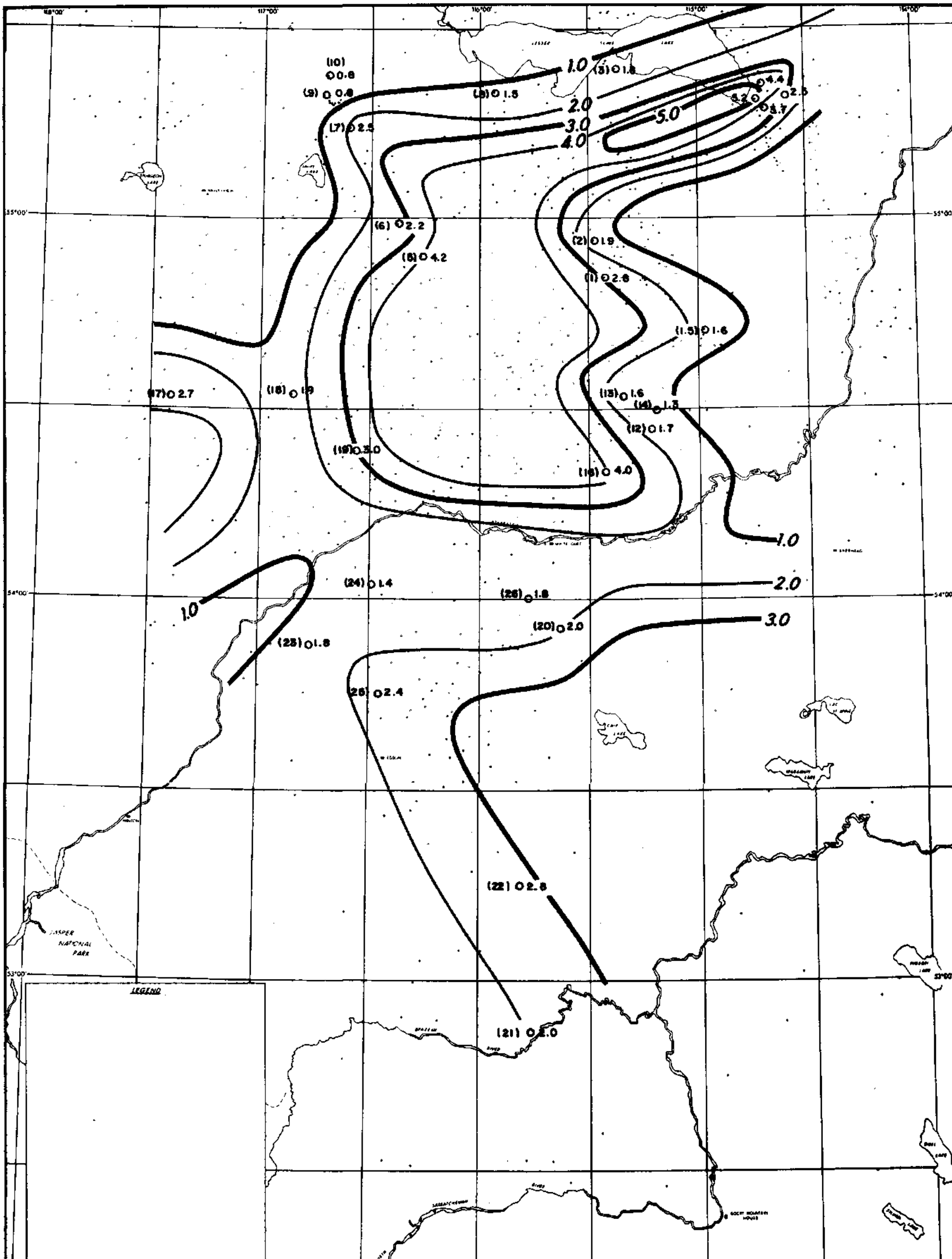
Micas, Chlorite and Glauconite

Micas are not abundantly represented in any sample. Muscovite is the dominant mica and was found mainly in the area close to the Peace River Arch, e.g. 9-17-73-18 W5M (#56) and 4-7-74-9 W5M (#11). However, biotite is found in a greater concentration west of Rge. 10 W5M (#78; Jansa and Fischbuch, 1974).

Chlorite has not been found in the microscopic analyses, although x-ray diffraction analyses indicate the presence of small amounts of chlorite in three wells. Similarly, no glauconite was encountered in the microscopic analyses. Shawa (1969), Thachuk (1968), and Kramers and Lerbekmo (1967) have not mentioned the occurrence of glauconite in the Utikuma, Nipisi and Mitsue areas. Jansa and Fischbuch (1974) state: "Most of the glauconite is present in the area from Snipe lake to Mitsue, where in rare instances, it may compose up to 8% of the total rock volume". High percentages of glauconite occur mainly in the Mitsue area, e.g. 4-18-71-4 W5M and 10-35-71-5 W5M wells.

Accessories

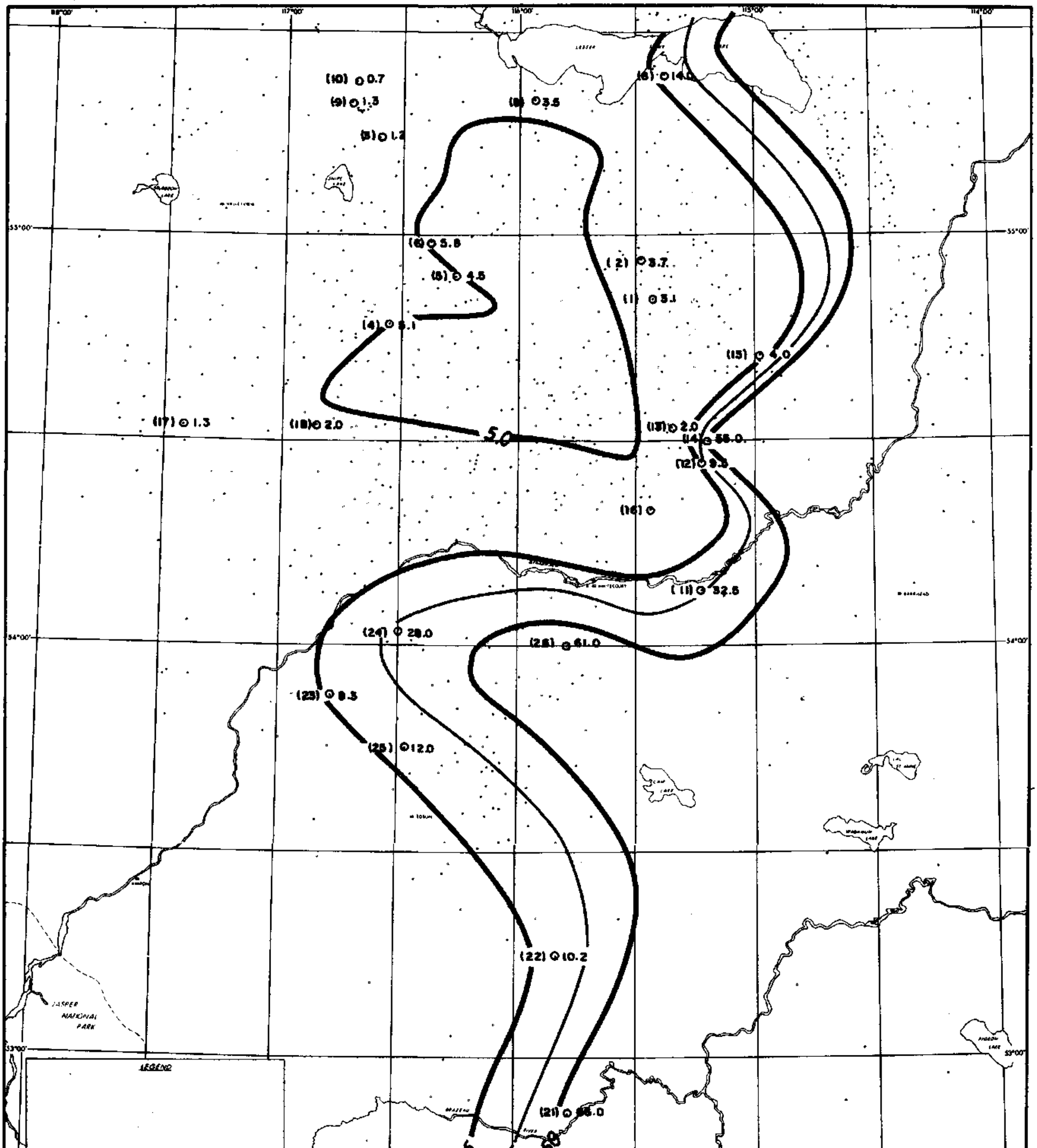
Rutile and magnetite are the only heavy minerals counted in the thin sections, although tourmaline, zircon and apatite have been spotted. Hematite forms a coating around the sand grains in certain wells. Accessory minerals occur only as isolated grains without layered concentrations. Kramers and Lerbekmo (1967) report the presence of zircon, normally in thin layers; Jansa and Fischbuch (1974) note rare concentrations of heavy minerals in thin layers (P. 16).



ATHABASCA RIVER AREA

FIG 8A

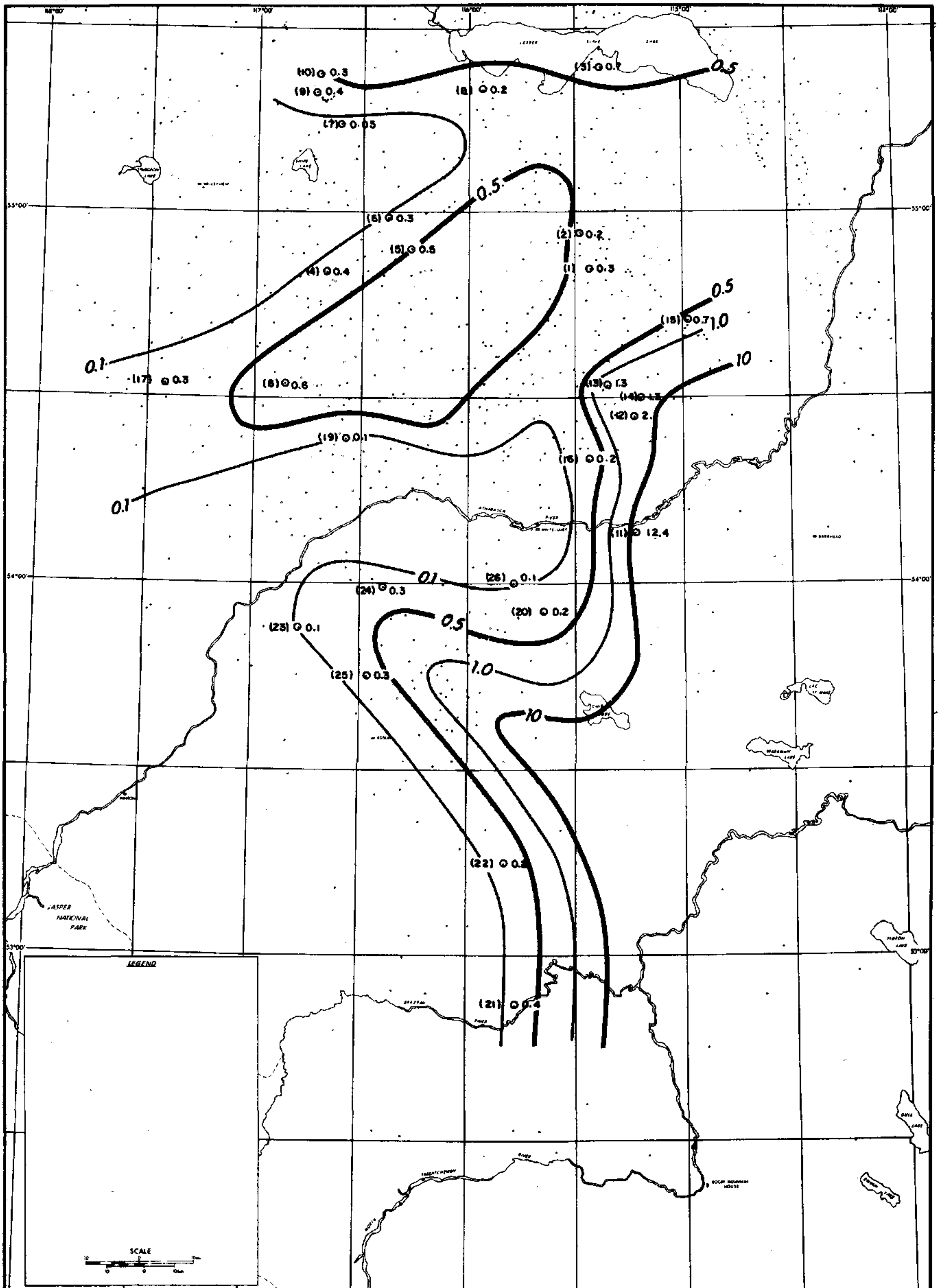
QUARTZ - FELDSPAR RATIO



ATHABASCA RIVER AREA

FIG 8B

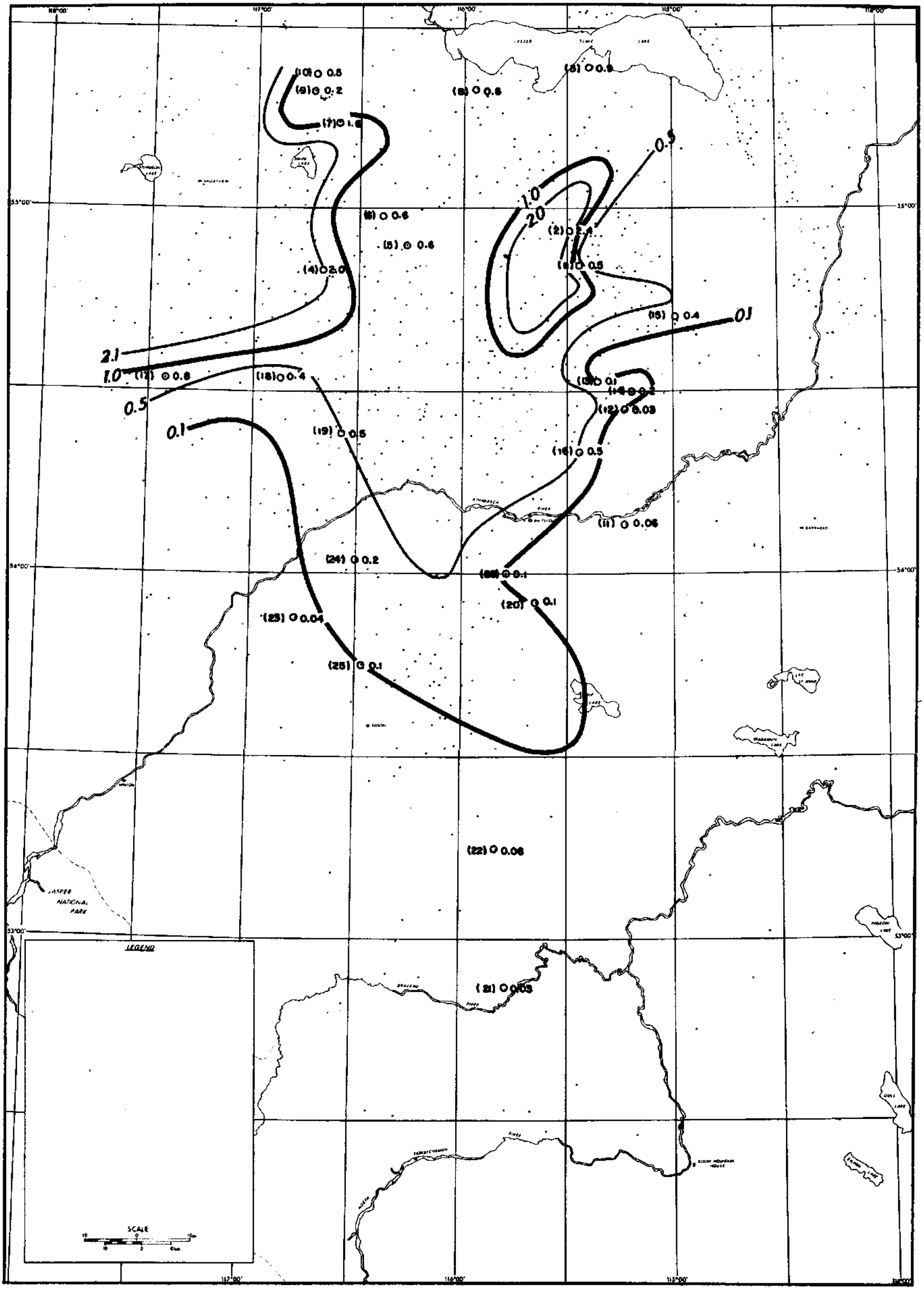
MONOCRYSTALLINE - POLYCRYSTALLINE QUARTZ RATIO



ATHABASCA RIVER AREA

FIG 8C

STRAIGHT UNDULOSE QUARTS RATIO



ATHABASCA RIVER AREA

FIG 8D

MICROCLINE K-FELDSPAR RATIO

Cement

The Gilwood Sandstone contains silica, carbonate and evaporite (anhydrite) cements, either separately or in combinations. The silica appears mostly as secondary overgrowth around the individual grains. The carbonate and anhydrite occupy mainly the pores. The evaporite is mostly the first cement and the carbonate appears as the second cement to be formed. The anhydrite cement is encountered as lath-like crystals or rosette crystals which suggest that they have grown freely in open spaces. Rottenfusser (1974) has arrived at a similar conclusion in his study of the Gilwood Sandstone north of the Arch. In many instances the carbonate shows the effects of recrystallization. Jansa and Fischbuch (1974 P. 19) state that the anhydrite cement is most common near the base of the Gilwood, but in the present study this could not be confirmed. The anhydrite cement is especially well developed in sandstones where little matrix is present, and which initially must have displayed good to excellent porosity. The Watt Mountain Formation is overlain by the Fort Vermilion Formation, which consists of thin, alternating limestone, dolomite, shale and salt and anhydrite beds. In the study area the Fort Vermilion Formation closely resembles the sabkha deposits of the Persian Gulf. One may thus conclude that the anhydrite cement had invaded the Watt Mountain Formation contemporaneously with the deposition of the Fort Vermilion Formation. Anhydrite cement has been found in the 9-17-73-18 W5M and 2-4-74-18 W5M wells. These two wells are closest to the Peace River Arch, where the Ft. Vermilion Formation has not been detected so far.

Sample #63 from the 10-26-59-9 W5M well indicates that anhydrite cement is not present in sandstones with a high amount of matrix. The matrix presumably impeded the movement of fluids through the formation.

Classification

The sandstones of the Gilwood Member have been classified on the basis of a scheme proposed by Pettijohn (Unpl; Krumbein and Sloss, 1963) (Appendix 5). The classification separates the coarser grains from the matrix. For this study Pettijohn's classification has been preferred over the others (e.g. Krynine, 1948; Travis, 1955) mostly because the classification relates directly to the major constituents while grouping them in a sensible way. Pettijohn's published "tetraedral classification" was not used for the reason that the sandstones contain only a few rock fragments (except the polycrystalline quartz). Most of the sandstone samples from the study area fall in the arkose subdivision. The sandstone higher in the section or closer to the eastern limits of the sand occurrence fall in the feldspathic sandstone and greywacke subdivisions.

C. Sedimentary Structures

1. General

In the course of the core study, the following sedimentary structures and related features were encountered:

a) Fining-upward and coarsening-upward sequences; abrupt lithologic changes; scoured surfaces; loadcasts.

b) Cross-bedding; linsen and flaser bedding; ripple drift laminations; wavy laminations; parallel bedding; bioturbated intervals.

c) The occurrence of more or less isolated pebbles; conglomeratic beds; rip-up clasts; clay galls.

d) Mottled appearance.

e) Homogenous layers.

Some of the above are defined in more detail.

Cross-bedding is used for both planar and trough cross-stratification. As the cores are only about 9 cm. in diameter, it is often impossible to distinguish between different types of cross-bedding.

The term "linsen and flaser" bedding is used for structures similar to those described by Reineck and Singh (1973, P. 97-103). They qualify these structures as follows: "A ripple bedding in which mud streaks are preserved completely in the troughs and partly on the crests is known as flaser bedding. Lenticular bedding shows well preserved sand lenses embedded within the mud layers. All transitions, from flaser bedding through wavy bedding to lenticular bedding exist".

"Rip-up clasts" are fragments of sediment, mostly silt and shale, which have been dislodged by current action and redeposited close to their place of origin, resulting in sharp, angular edges. A relatively strong force is needed to rip-up clay after it has been deposited (Hjulstrom, 1935). Such ripped-up clasts are usually rounded over in a very short distance. In contrast, rounded balls of clay and/or silt survive as claygalls for a considerable distance before breaking up. They are therefore not necessarily an indication of the environment in which they have been deposited.

A "mottled" appearance is normally the result of burrowing action of animals in layered deposits; in the study area a mottled appearance mostly indicates a difference in cementation which can be related to differences in grain size.

The expression "no structure" is used when no structures are apparent and in cases where it cannot be determined that the absence of structures is due to bioturbation the term "homogeneous beds" is used.

Sedimentary structures have been studied, using the cores of 47 wells throughout the area. Map 6 shows the locations of these wells, the S.P. Log responses over the Watt Mountain interval, the cored intervals and the structures encountered in the cores.

The cored intervals of the following wells did not match the correspondent intervals on the well mechanical logs. In such cases it is customary to adjust the drilling depth to the depth on the logs on the assumption that the latter are more accurate.

The cored interval of the 5-9-72-18 W5M well was adjusted upward by 2.1 m. to correspond with the log curves. The core of the 12-6-72-18 W5M was 1.5 m. too low. Adjustments were also made in the 10-18-64-19 W5M:1.8 m. too low and the 5-32-62-18 W5M; 2.7 m. too low, and in the 11-11-73-13 W5M well: 1.8 m. too high.

Few sedimentary structures are restricted to one single environment and therefore any particular environment can only be recognized by a group of structures or a specific sequence of structures. Environmental interpretations based on core studies are sometimes limited when the lateral extend or variation is signficant. The necessity to consider the paleogeographic setting when making a final interpretation, becomes obvious in most instances.

Sedimentary structures have been divided into two groups:

1) High energy (H.E.) sedimentary structures

2) Low energy (L.E.) sedimentary structures

Some structures of the H.E. group are: high and low angle cross-bedding, sharp basal contacts and scours, conglomeratic beds, clay galls and rip-up clasts; typical for the H.E. group is a relative lack of bioturbation. The L.E. group is generally characterized by linsen and flaser bedding, ripple drift and wavy laminations, parallel bedding, load casts, and intensive bioturbation.

Some sedimentary structures can be indicative of both the H.E. and L.E. groups: e.g. parallel bedding can be a product of both the upper and lower flow regimes. Rip-up clasts could be fragments of an indurated clay layer ripped-up by current action, but they can also represent remnants of a mud-cracked surface.

The sedimentation of the Gilwood Sandstone in the northwestern part of the study area invariably begins with H. E. conditions, which near the top of the stratigraphic interval change to an L. E. environment. The thickness of the H. E. environment decreases generally towards the east and southeast. Changes can occasionally be attributed to the proximity to areas with high energies such as channels and beaches. (Viz. 10-18-64-19 W5M and 4-4-66-24 W5M). This H. E. — L. E. sedimentation pattern persists eastward to about Rge. 10 W5M. A L. E. environment existed east of Rge. 10 as is suggested by the sedimentary structures. In the Mitsue area, the Gilwood Sandstone has been deposited in more agitated surroundings as is shown by Kramers & Lerbekmo (1967, Plates 1 and 2). Sedimentary structures such as those reported for the Mitsue area have not been encountered in the wells between the Mitsue oilfield and Rge. 10 W5M.

2. Detailed Description

Eight wells were chosen for a more detailed description; they are the 4-7-74-9 W5M, the 11-11-73-13 W5M, the 2-21-73-13 W5M, the 4-4-66-24 W5M, the 10-5-65-23 W5M, the 5-35-62-18 W5M, the 7-7-57-12 W5M and the 2-25-50-14 W5M wells.

The sedimentary structures found in the cores from these wells are indicated on the left side of Figs. 9 through 16. A vertical sequence per core box(approximatley 1.5 m.) has been listed in a horizontal line: left to right reads from top to bottom. The core box intervals are indicated to the right of the lithology column. The vertical scale of Figs. 9-16 is 1:240 (5" : 100').

The I.O.E. Swan Point 4-7-74-9 W5M Well

Fig. 9 portrays the Watt Mountain Formation sediments in the Swan Point well. The top 90 cm. were not cored. The sediments can be attributed to five cycles: one coarsening-upward and four fining-upward cycles. Sedimentation started with a coarsening-upward cycle, grading from a green shale without any visible structures through a silty shale with some flaser and linsen bedding to a sandy shale which is bioturbated and exhibits some cross-bedding (Cycle #1).

The next cycle is the first of four fining-upwards cycles; it starts with the upper part of the sandy shale previously described; the sandy shale grades into a featureless shale (Cycle #2).

A medium grained, beige-brown coloured sandstone overlies this shale with a sharp contact. This sandstone contains floating pebbles and some thin conglomeratic layers, but no sedimentary stuctures are apparent. The sandstone is overlain by a green, fine grained, sandstone. The green colour is due to a matrix of green argillaceous material which constitutes approximately 10% of the rock. Cross-bedding is the main sedimentary structure of the green sandstone. The top part of this cycle is a sandy shale with abundant linsen and flaser bedding (Cycle #3).

This is abruptly overlain by a beige, very coarse grained, sandstone, which contains some conglomeratic streaks and cross-bedding. The beige sandstone grades into a slightly finer grained interval in which some cross-bedding is apparent and which is followed by another green, coarse grained, sandstone (20% argillaceous matrix) with cross-bedding. The second green sandstone grades into a shaly sandstone-medium to fine grained with linsen and flaser bedding - and higher in the section this gives way to a sandy shale with linsen and flaser structures (Cycle #4).

The last cycle commences with a sequence of interbedding sandstone and shale beds. The sandstone is coarse to fine grained, and its colour is beige. The shale is green and contains often floating sand grains. Linsen and flaser bedding and wavy laminations are the dominant structures. The sandstone becomes finer grained towards the top, where also rip-up clasts and cross-bedding have been found. The top of this cycle is formed by sandy shale with linsen and flaser bedding and bioturbation (Cycle #5).

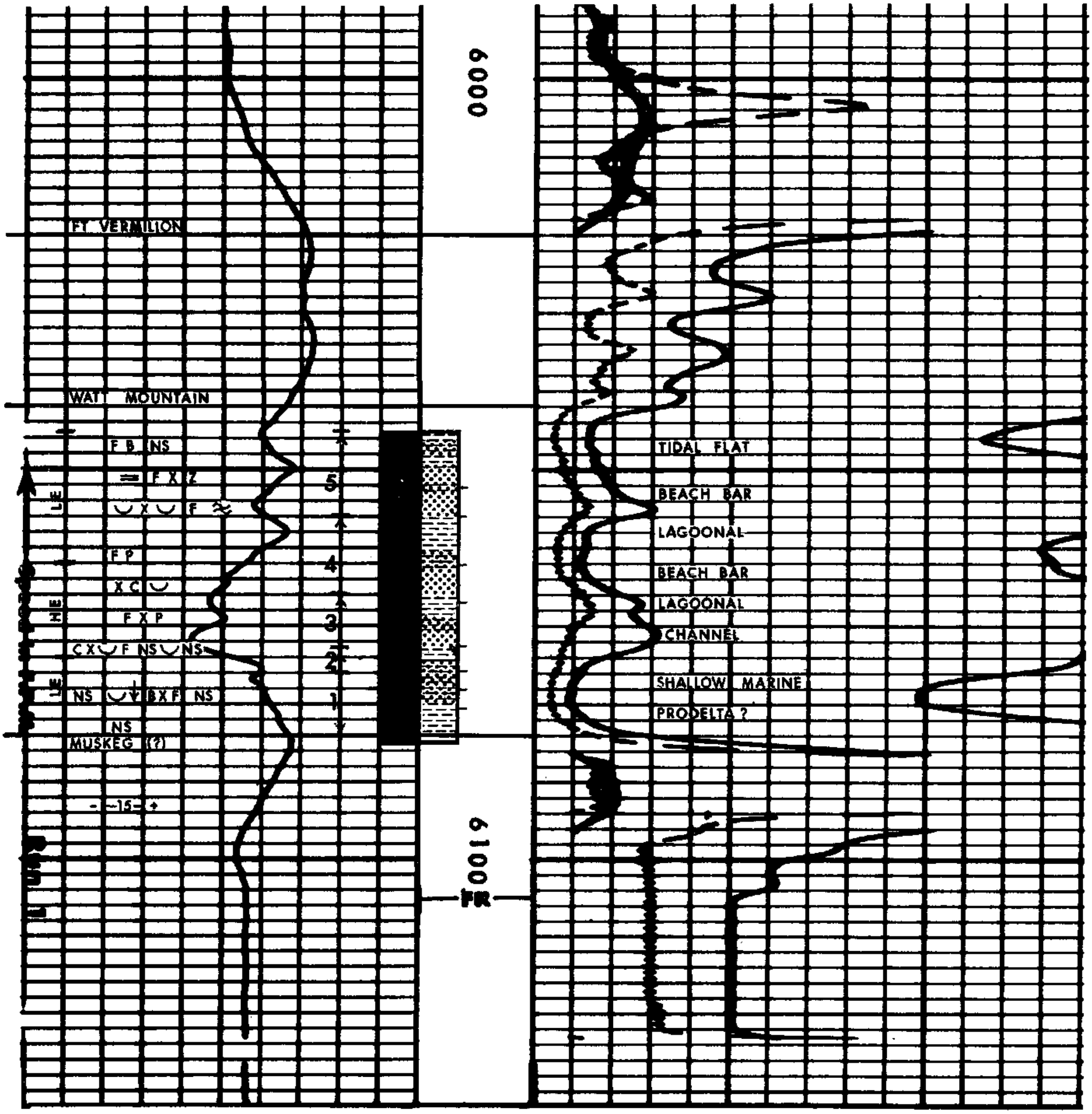
The Imp. Joussard 11-11-73-13 W5M Well (Fig. 10)

The whole Watt Mountain Formation is cored in this well. The core was adjusted 1.8 m. downwards. Seven fining-upwards cycles have been recognized. The lowermost cycle overlies unconformably a sequence of limestone, limy siltstone and shale. The first cycle starts with a medium to fine grained, grey sandstone with cross-bedding. The fine grained sandstone grades into a grey, fine to very fine grained sandstone, also with cross-bedding. An abrupt change to a grey, coarse to fine grained sandstone, announces the start of the second cycle.

This sandstone contains floating pebbles and cross-bedding. It grades into a green-brown, medium to very fine grained, cross-bedded sandstone with a few layers of coarse grains in the bottom part. This sandstone grades into a green, cross-bedded argillaceous sandstone. The top is formed by a sandy shale, green and red in colour and with much linsen and flaser bedding.

A green-brown coarse to fine grained sandstone of cycle 3 abruptly overlies the shale. A few shale lenses, possibly some rounded to subrounded, rip-up clasts occur in the lower part of the sandstone. Cross-bedding is the main structure. The sandstone gradually changes into green argillaceous sandstone. In some instances the sand grains are floating in the argillaceous matrix. Crossbeds are visible, changing to abundant linsen and flaser bedding in the top part of the interval.

The fourth cycle starts with a sharp contact; a medium to very coarse grained sandstone with lenses of pebbles in the basal part becomes gradually a cross-bedded, medium grained sandstone, which changes into a green, argillaceous sandstone with linsen and flaser bedding. The sedimentation continued with a brown-grey, coarse to fine grained, sandstone (Cycle 5); the contact with cycle 4 is sharp.



ENVIRONMENTAL INTERPRETATION OF S.P.-RESISTIVITY LOGS
FROM THE WATT MOUNTAIN FORMATION SEDIMENTS
IN THE
SWAN POINT WELL
4-7-74-9W5M

See Fig. 9-A for explanation of legend

LEGEND FOR FIG. 9 THROUGH 16

↑ = Finding Upwards

↓ = Coarsening Upwards

B = Bioturbation

X = Cross-Bedding

F = Linsen and Flaser

◡ = Sharp Lower Contact

⏝ = Scour

P = Pebbles

C = Conglomerate

R = Ripple Drift Lamination

NS = No Structures

Z = Rip-up Clasts

≈ = Wavy Laminations

═ = Parallel Bedding

$\bar{\sigma}$ = Loadcasts

G = Claygalls

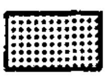
M = Mottled

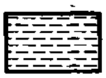
Rd Gn = Red and Green Shales

LE = Low Energy

HE = High Energy

 Conglomerate

 Sandstone

 Shale

Cross-bedding of the fine grained sandstone is evident and the individual sandstone beds show small scale grading (fining-upward). A green-grey argillaceous, fine grained sandstone overlies with a gradual contact.Cross-bedding and linsen and flaser bedding has been recognized. The sandstone becomes progressively more argillaceous with more abundant linsen and flaser bedding. Red shales occur in this interval also.

The sixth cycle start abruptly with a coarse to fine grained sandstone with cross-bedding overlying a scoured surface. Thin layers of coarse grains occur, especially in the basal part of the sandstone which also contains some rip-up clasts. The sandstone changes slowly into an argillaceous sandstone and subsequently into a sandy shale. Both shale and sandstone zones display abundant linsen and flaser bedding and bioturbation in the sandy shale.

The seventh cycle begins with a grey-beige, medium to fine grained sandstone. It displayed cross-bedding and some rip-up clasts and it grades into a fine grained, argillaceous sandstone with rounded anhydritic grains in the uper part. Cross-bedding in the lower part and linsen and flaser bedding in the higher parts are evident. This cycle ends with a sandy shale which is abundantly bioturbated. The sandy shale shows some linsen and flaser bedding. The contact with the Fort Vermilion Formation is very gradual and has not accurately been determined.

The Penzoil - I.O.E. Joussard 2-21-73-13 W5M Well (Fig. 11)

The Watt Mountain Formation of the Penzoil - I.O.E. Joussard well contains evidence for five major cycles. A brown silty and sandy carbonate of the Cambrian Eldon Formation is uncomformably overlain by a thin green shale layer of possible Cambrian age which, in turn, is followed by a grey-brown, coarse to fine grained sandstone (Cycle 1). The contact of the shale with the sandstone is a scour surface. The scour fill is generally coarser and rip-up clasts are more prominent in this interval. The sandstone becomes gradually medium to fine grained. Cross-bedding is dominant. The top of the first cycle contains a grey-brown argillaceous sandstone possibly with some oilstain and a sandy shale with linsen and flaser bedding.

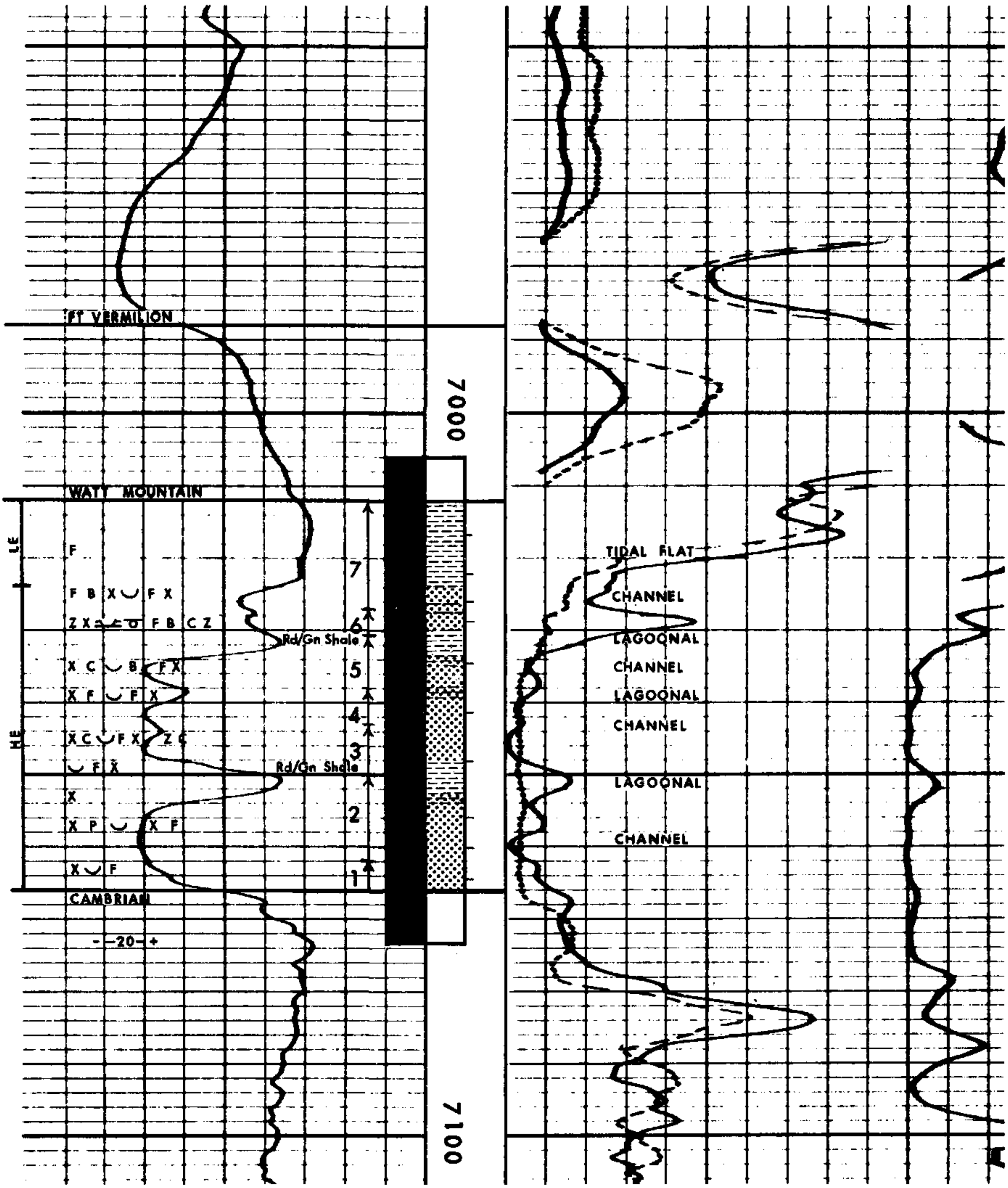
The second cycle starts with thin layers of brown sandstone, medium to fine grained, and with cross-bedding, followed by a green and brown (red) coloured sandy shale with linsen and flaser bedding and possibly some bioturbation. The sand grains are quite often floating in the argillaceous matrix. The shale also shows irregular patches of a brown (red) colour. There is no apparent difference in the composition of the green vs. the brown shale. The green and brown sandy shale is succeeded by a green sandstone, medium to fine grained.

Shaly rip-up clasts occur in this sandstone. The shale contains floating sand grains. The sandstone grades into a green coloured, fine grained sandstone. Both sandstones have a mottled appearance and sedimentary structures are lacking. A thin green shale bed terminates the third cycle.

It is overlain by a brown, medium to fine grained sandstone with cross-bedding (fourth cycle). The brown colour is due to oilstaining and not to a brown argillaceous matrix. This sandstone gradually becomes fine to very fine grained. It is overlain by a green and brown (red) sandy shale, with abundant linsen and flaser bedding.

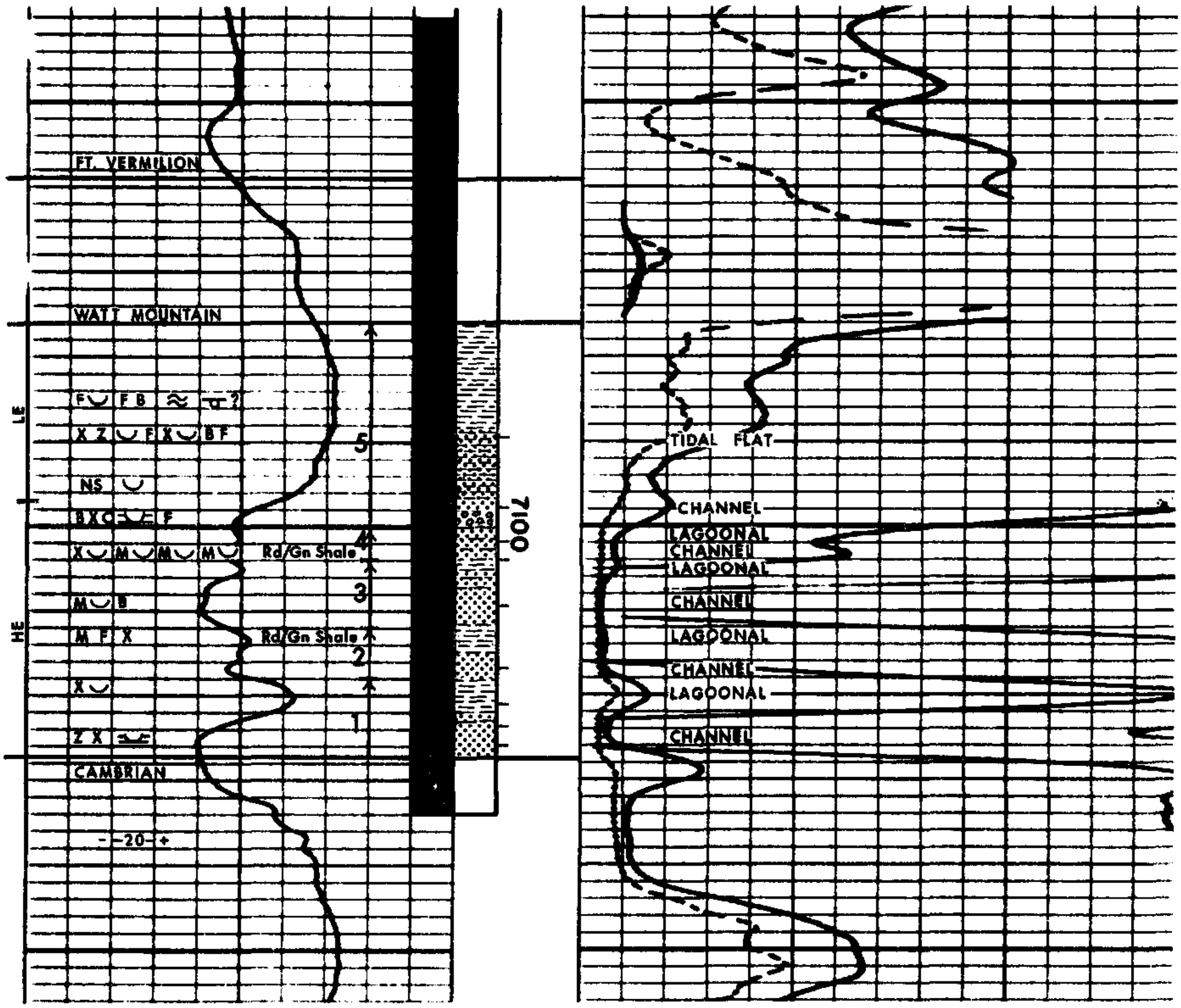
A conglomeratic sandstone announces the beginning of the last (fifth) cycle. This cycle has been subdivided into three subcycles, two of which are about 75 cm. thick; the uppermost subcycle is about 2.1 m. thick. It also constitutes the end of the sand deposition in the Watt Mountain Formation.

The conglomeratic sandstone of the first subcycle has scoured into the underlying shale. Cross-bedding has been found in this sandstone. There is a rapid fining-upward of the conglomeratic sandstone through a fine grained sandstone into a thin shale with sandstone interbeds and floating sand grains. Bioturation has virtually destroyed all sedimentary structures of the thin shale. The second subcycle begins with a medium grained sandstone and this sandstone grades into a sandy shale with abundant linsen and flaser bedding and bioturbation. A thin sandstone layer (third subcycle) containing rip-up clasts and cross-bedding overlies the foregoing. It rapidly changes in a sandy shale with wavy lamination, bioturbated intervals, linsen and flaser bedding and load-casts. This shale becomes less sandy toward the top, where it grades into the black, calcareous and evaporite-bearing shales of the Fort Vermilion Formation.



ENVIRONMENTAL INTERPRETATION OF S.P.-RESISTIVITY LOGS
FROM THE WATT MOUNTAIN FORMATION SEDIMENTS
IN THE
IMP. JOUSSARD WELL
11-11-73-13W5M

Note: Cores adjusted 6 feet downwards
See Fig. 9-A for explanation of legend



ENVIRONMENTAL INTERPRETATION OF S.P.-RESISTIVITY LOGS
FROM THE WATT MOUNTAIN FORMATION SEDIMENTS
IN THE
PENZOIL I.O.E. JOUSSARD WELL
2-21-73-13W5M

See Fig. 9-A for explanation of legend

The Pan Am C-1 Ante Creek 4-4-66-24 W5M Well (Fig. 12)

Almost the entire Watt Mountain interval has been cored in this well, with the exception of approximately 60 cm. at the bottom and 1.8 m. in the middle.

The base of the cored interval starts with a coarse grained sandstone with some cross-bedding and oilstaining. Upwards it fines slightly into a medium grained, scantly argillaceous sandstone, (Cycle 1) which is overlain by a conglomeratic sandstone (Cycle 2). The contact has been scoured. Some rounded pebbles attain diameters of up to 20 mm. The conglomeratic sandstone grades upwards into a medium to fine grained sandstone with cross-bedding, and then into a sandy shale. Linsen and flaser bedding and bioturbation are visible.

Above the 1.8 m. of missing core, a fine grained sandstone withcross-bedding (Cycle 3) is gradually followed by a argillaceous sandstone containing cross-bedding linsen and flaser bedding and bioturbation. The cored section ends with a sandy shale with abundant bioturbation and some indication of linsen and flaser bedding.

The Pan Am-Mobil E-1 Ante Creek 10-5-65-23 W5M Well (fig. 13)

The lowermost 30 cm. of the Watt Mountain Formation is the only part that has not been cored. First cycle: The core starts with a grey, conglomeratic sandstone, with cross-bedding and clay galls. The sandstone has a mottled appearance; it grades into an argillaceous sandstone with linsen and flaser bedding. Cycle 2: This is separated with a sharp contact from a cross-bedded sandstone, which contains rip-up clasts and which fines into a shaly sandstone with cross-bedding. Cycle 3: A cross-bedded conglomeratic sandstone overlies the shaly sandstone with a scoured contact, and the conglomeratic sandstone becomes an argillaceous sandstone. This in turn has been scoured by the cross-bedded, conglomeratic sandstone of the fourth cycle. Clay galls are present higher up in the section. This coarse sandstone makes way for a medium to fine grained sandstone with cross-bedding, followed by a fine grained sandstone and an argillaceous sandstone, both with interbedded sandy shale layers. Both the fine grained sandstone and argillaceous sandstone contain bioturbation and faint indications of linsen and flaser bedding.

The contact with the overlying cross-bedded, fine grained sandstone is sharp. Ripple drift laminations are also visible in this sandstone. It is abruptly followed (scoured contact) by a coarse grained sandstone of the fifth cycle which has a mottled appearance and is cross-bedded and conglomeratic. The coarse grained sandstone grades into a fine grained sandstone. The cycle ends in a thin veneer of shale. Sixth cycle: sedimentation continued with a coarse grained, cross-bedded, mottled sandstone, which fines into an argillaceous sandstone with linsen and flaser bedding. The argillaceous sandstone gradually changes into a sandy shale which becomes less sandy toward the top. The upper boundary of the Watt Mountain Formation is difficult to define, but it has tentatively been placed at 11,202 feet.

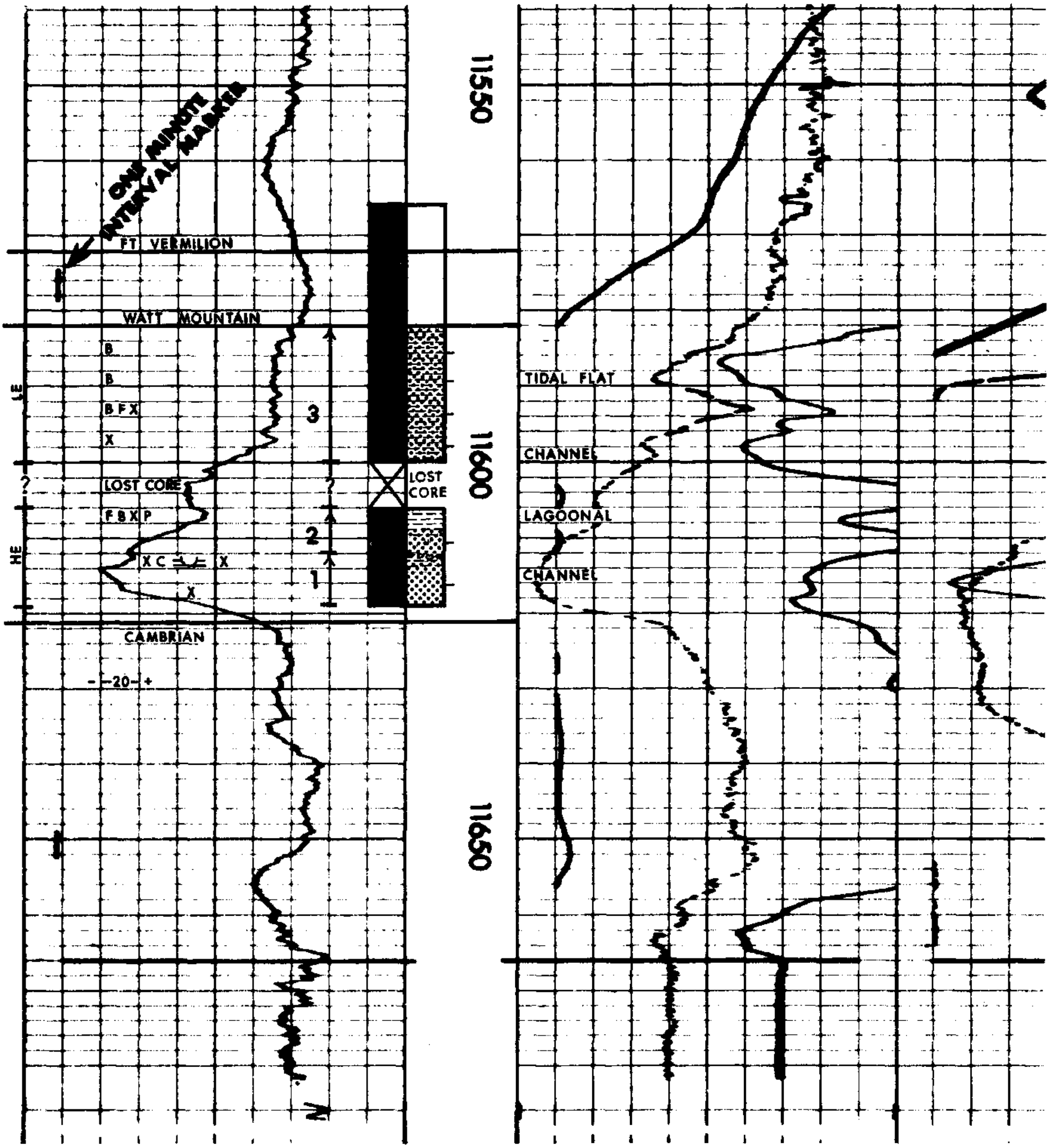
The Cal. Stan - Gulf Kaybob 5-35-62-18 W5M Well (Fig. 14)

The depth of the cores have been adjusted upwards by 2.7 m. A 60 cm. gap exists between cores #16 and #17 (see Fig. 14). The Watt Mountain Formation starts with a conglomeratic and cross-bedded sandstone (first) cycle. The conglomeratic sandstone continues into core #17, where it gradually changes into an argillaceous sandstone which is cross-bedded and contains some coaly streaks.

The conglomeratic sandstone is overlain by a coarse grained structureless sandstone with some conglomeratic streaks and also some rip-up clasts (2nd cycle). This sandstone is followed by a fine grained sandstone with interbedded shale streaks. The sandstone exhibits linsen and flaser bedding, and traces of glauconite. A sandy shale represents the end of this cycle. This shale becomes less sandy upwards and grades into the Fort Vermilion Formation.

The Pacific Mahaska 7-7-57-12 W5M Well (Fig. 15)

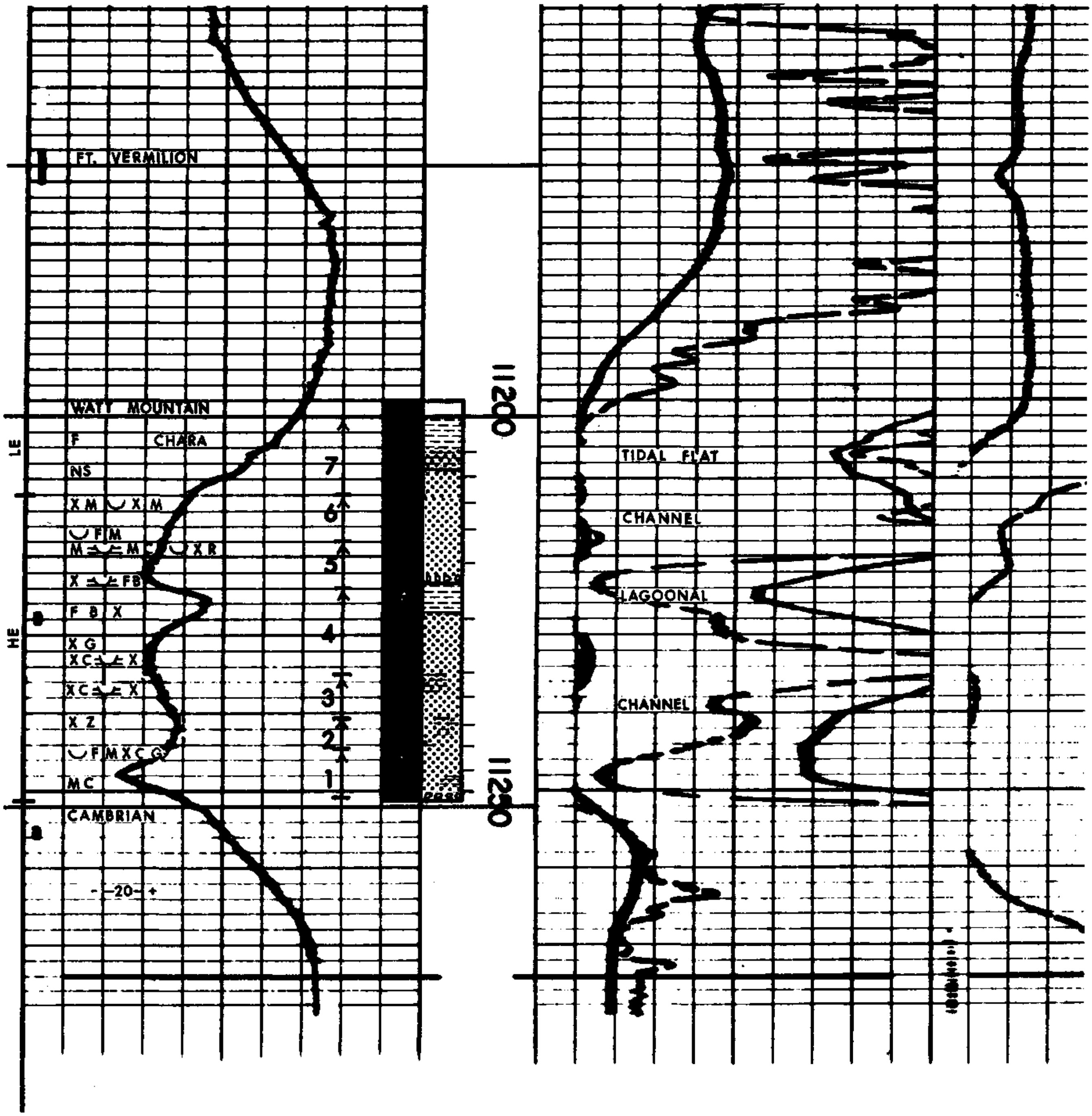
The Watt Mountain Formation has been partially cored in this well; fortunately the cored interval covers the essential part of the Gilwood Member. The core begins with what could be a coarsening upwards (first) cycle. An argillaceous sandstone with minor cross-bedding and some bioturbation, grades into a sandstone, slightly less argillaceous, and with abundant cross-bedding. This sandstone could also be the basal unit of a fining upwards second cycle, since it gradually changes into a shale with minor sand. An argillaceous sand (third cycle) with minor cross-bedding follws and it, in turn, gives way to a slightly sandy shale. The next, fourth, cycle consists of a sandy shale with some linsen and flaser bedding. Indications of bioturbation exist at the base of the sandy shale, and in the shale at the top. The shale is abruptly overlain by a medium grained sandstone (fifth cycle) with minor cross-bedding. The sandstone grades into an argillaceous sandstone and later into a sandy shale.



ENVIRONMENTAL INTERPRETATION OF S.P.-RESISTIVITY LOGS FROM THE WATT MOUNTAIN FORMATION SEDIMENTS IN THE

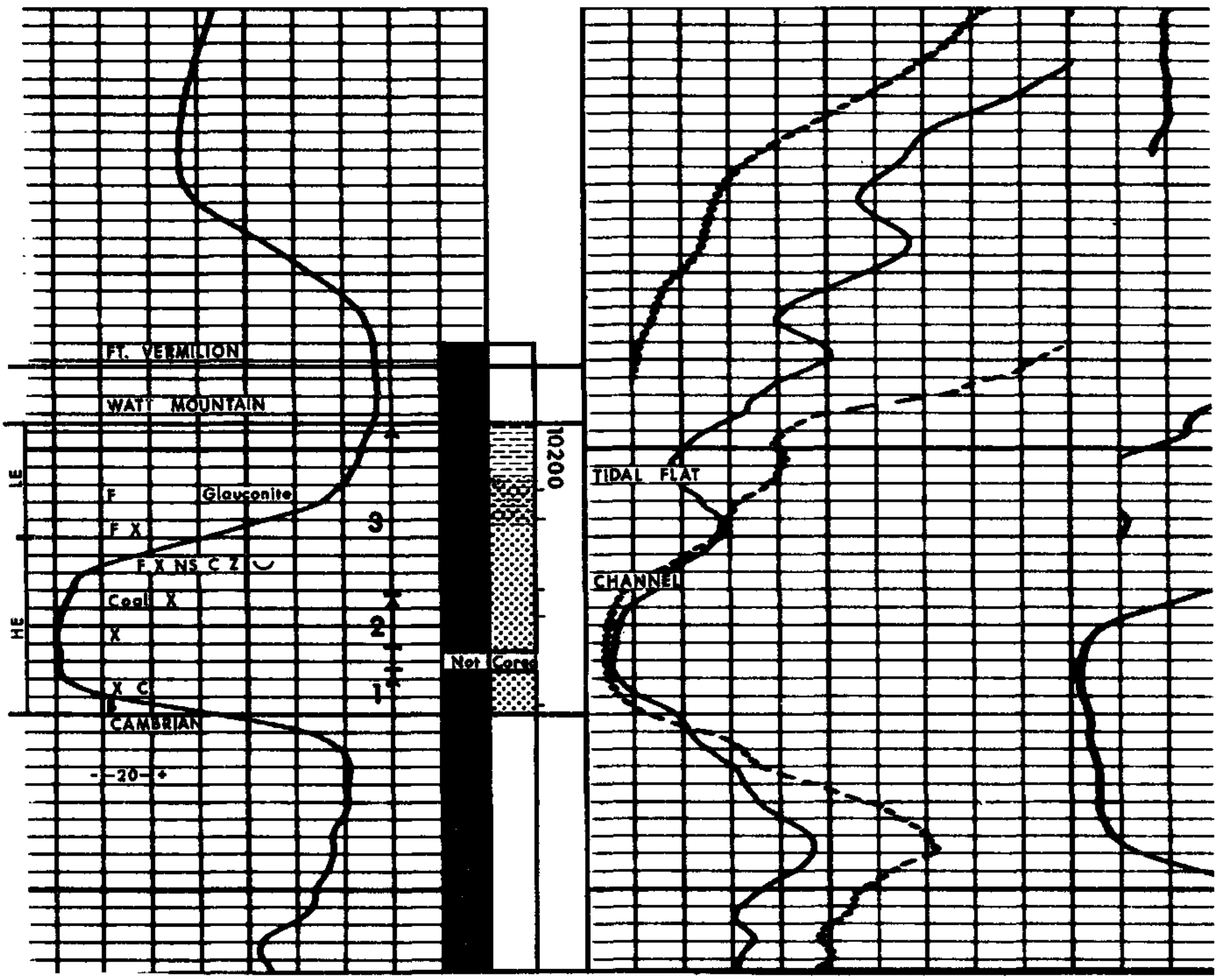
PAN-AM C-1 ANTE CREEK WELL
4-4-66-24W5M

See Fig. 9-A for explanation of legend



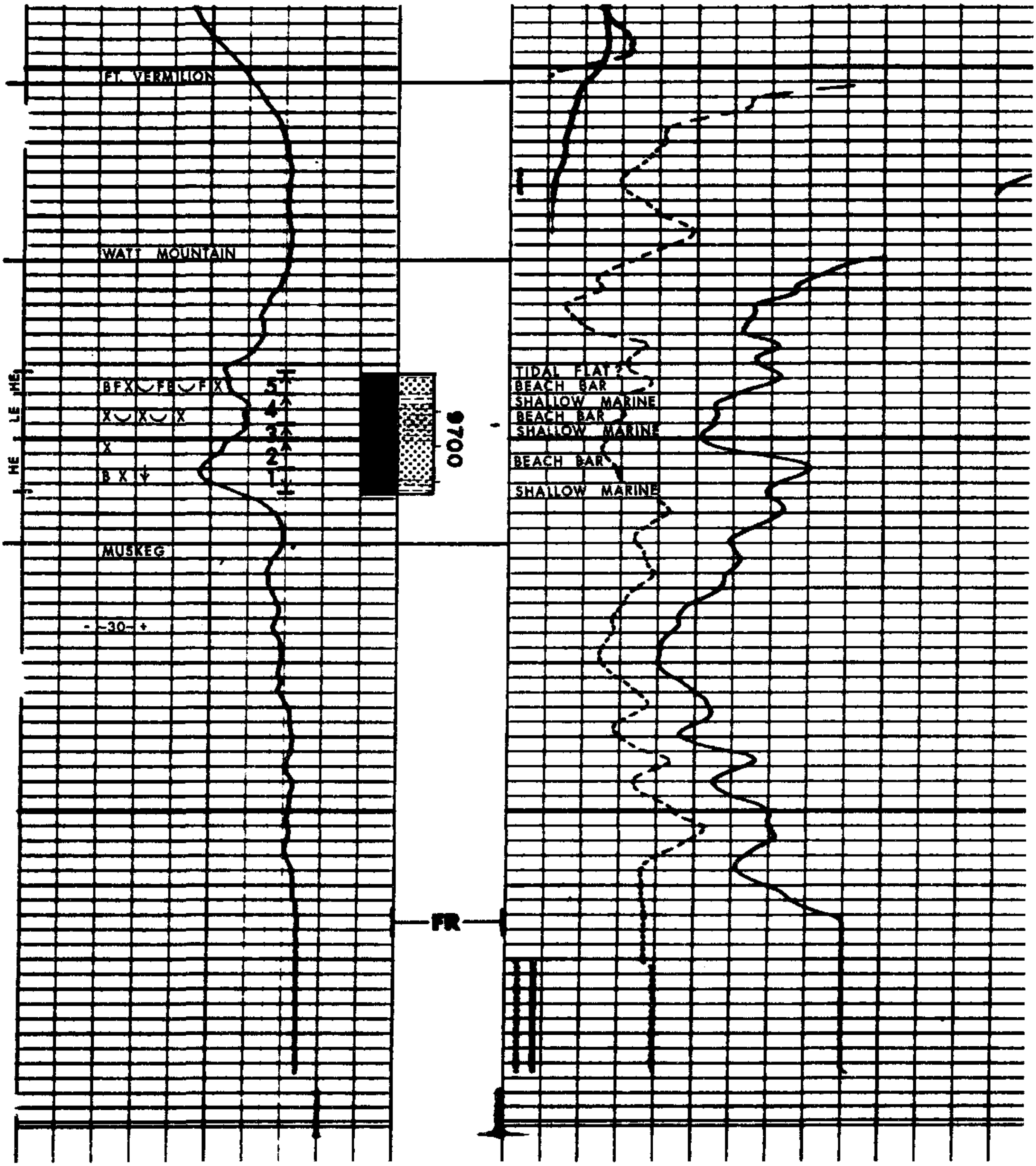
ENVIRONMENTAL INTERPRETATION OF S.P.-RESISTIVITY LOGS
FROM THE WATT MOUNTAIN FORMATION SEDIMENTS
IN THE
PAN-AM E-1 ANTE CREEK WELL
10-5-65-23W5M

See Fig. 9-A for explanation of legend



ENVIRONMENTAL INTERPRETATION OF S.P. - RESISTIVITY LOGS
FROM THE WATT MOUNTAIN FORMATION SEDIMENTS
IN THE
CAL. STAN. - GULF KAYBOB WELL
5-35-62-18W5M

Note : Cores adjusted 9 feet upwards
See Fig. 9-A for explanation of legend



ENVIRONMENTAL INTERPRETATION OF S.P.-RESISTIVITY LOGS FROM THE WATT MOUNTAIN FORMATION SEDIMENTS IN THE

PACIFIC MAHASKA WELL

7-7-57-12W5M

See Fig. 9-A for explanation of legend

The Imp. Nipac 2-25-50-14 W5M Well (Fig. 16)

Cycle 1: The sequence starts with coarse grained, cross-bedded sandstone above the base of the Watt Mountain Formation. Some floating pebbles were found. The sandstone changes gradually into a medium grained, cross-bedded sandstone. The sandstone changes into a sandy shale with abundant linsen and flaser. Cycle 2: An argillaceous sandstone in which linsen and flaser bedding is evident, overlies the shale with a sharp contact. It is overlain by a bioturbated sandy shale and a clean shale. The uppermost cycle, (Cycle 3), in the core commences with a cross-bedded sandstone which is followed by an argillaceous sandstone with minor cross-bedding. The sandstone grades into a bioturbated sandy shale with some indications of linsen and flaser bedding. The top of this cycle is formed by a shale which becomes increasingly less sandy. The contact with the Fort Vermilion Formation is very gradual.

Other Observations

Coal:

Coal has been found in four wells: 10-33-63-23 W5M; 12-1-64-24 W5M; 5-35-62-18 W5M; and 6-15-58-17 W5M. Coal may be used as an enviromental indicator, e.g. in those cases where the connecting rootlet bed has been preserved. A study of the reflectance of the coal may reveal that the coal originates from single logs or peat beds. The coal found in the study area consists of fusaine or charcoal, which can be of many origins. Fusaine coal was therefore not used in the determination of the depositional environment.

Coquinas:

Coquinas are part and parcel of many clastic sedimentary sequences. They can develop in abandoned delta lobs, for example, where transgressive beach ridges, consisting of shell material have been brought in by wave action (Kanes 1970). Coquinas have been encountered in two wells, but so far not within the Watt Mountain interval. The two wells in which the coquinas were found are located in 9-17-73-17 W5M and in 2-4-74-18 W5M, close to the Peace River Arch. In both cases the coquina marks the bottom of the Swan Hills Formation. In this area the base of the Swan Hills Formation consists of a sandy sequence, overlain by a more calcareous sequence, indicating proximity to ancient shorelines.

Red (Brown) and Green Shales:

The red (brown) and green shales encountered in the cores throughout the area contain a variable amount of very fine grained plant debris. It appears that the amount is greater in the green than in the red (brown) shales. Occasionally the determination of plant debris can be an optical illusion, when the colour contrast between the black debris and the bright green shale is greater. McBride (1974) notes that the amount of organic matter in red beds is smaller then in green or grey strata (0.11% vs. 0.43)[1].

Shales with red (brown) and green coloured patches occur in certain parts of the study area. This occurrence has been indicated on map 6. McBride (1974, p. 760) explains that: "red, green and purple rocks are restricted to delta - plain facies..." and that "green beds (are) formed by bleaching of red (or protored) beds by interstitial percolation of reducing water derived largely from fluvial channels overlying the green beds". The colour of the shale therefore may thus be an indication of a particular environment of deposition.

SEDIMENTOLOGY

I. Main Sedimentological Units and Depositional Environments

Five environments have been interpreted for the study area.

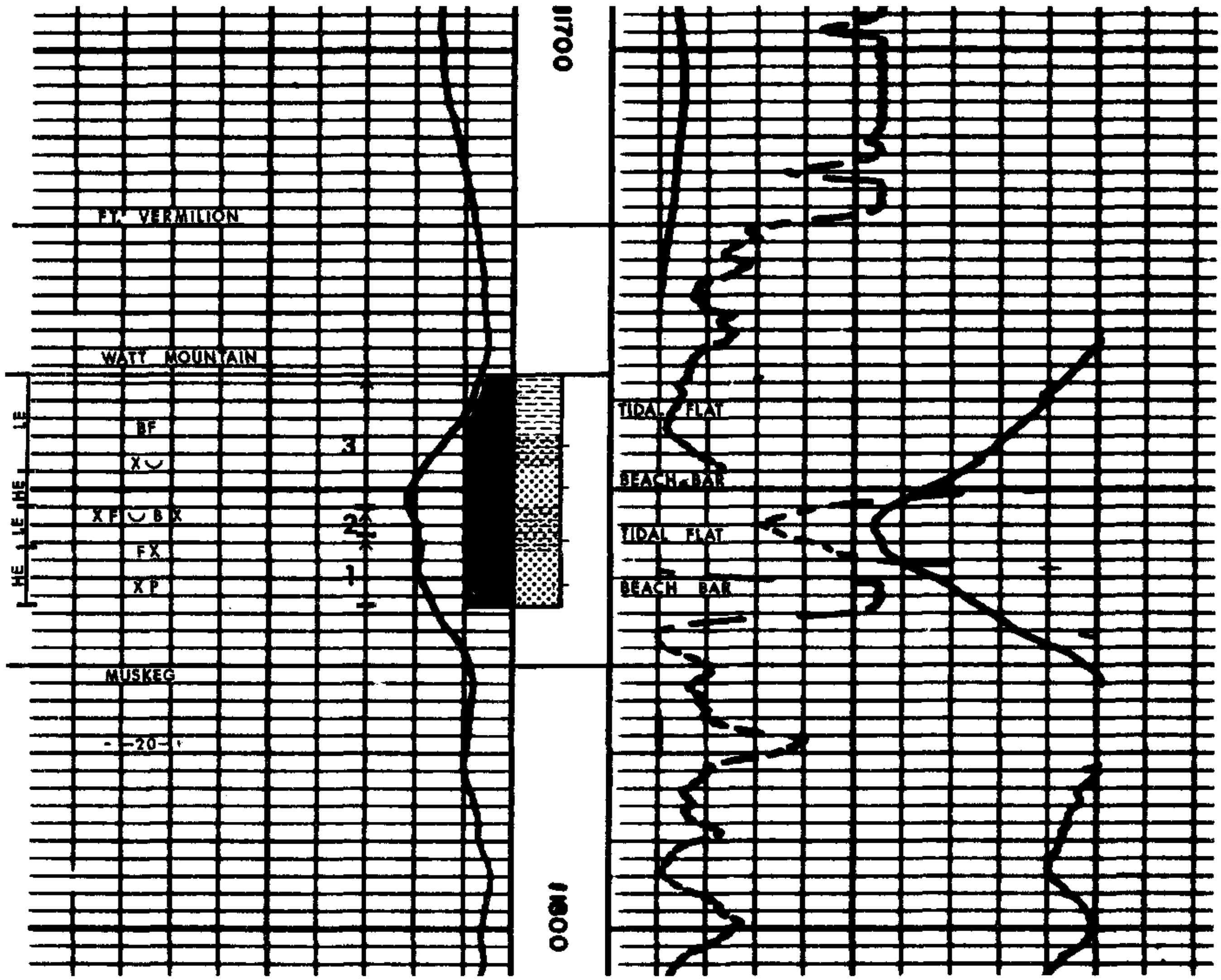
A. Shallow Marine and Lagoonal Environments (Plate I)

Shallow marine and lagoonal environments have been lumped into one unit because usually it is impossible to distinguish between them. The characteristic shallow marine-lagoonal strata consist of interbedded layers of shale and sandstone. There may be extensive burrowing, depending on the rate of sedimentation. The amount of sand depends on:

a) supply of sand from the continent

b) mechanism of distribution

1) Red shales point to oxygen rich environment of deposition, whereas green shales point to a reducing environment. This could explain the absence of plant debris in the red shales.



ENVIRONMENTAL INTERPRETATION OF S.P.-RESISTIVITY LOGS FROM THE WATT MOUNTAIN FORMATION SEDIMENTS IN THE

IMP NIPAC WELL
2-25-50-14 W5M

See Fig. 9-A for explanation of legend

c) proximity to a channel

d) depth of water and turbulence

e) the presence of a sandbody in the underlying strata, which may be reworked

f) four combinations of these

Plant debris may be more abundant in the lagoonal facies and will likely be fine grained. (Michaelis and Dixon, 1969, Lithofacies B).

B. Beach Bar Environments (Plate 2)

The beach bar designation used here includes sediments deposited on offshore bars, beaches and beach dunes. Beaches and beach dunes may occur either on the mainland or on barrier islands. Thin, smooth horizontal laminations, low angle truncations, some ripple drift laminations, some burrowing and rare glauconite are the main features for this environment. Fossils are generally scarce (Michealis and Dixon, Lithofacies A).

C. Channel Environments (Plate 3)

All channels - tidal, river distributary, fluvial, etc. show similar depositional features. They are characterized by abundant medium cross-strata, horizontal laminations, clay galls, upward decrease in grain size and usually sharp basal contacts. Pebbles are most common in fluvial channels whereas shells are a common occurrence in shallow marine channels. Slump structures occur sometimes due to bank caving. Burrows are usually scarce, although more abundant in the tidal zone (Michaelis and Dixon, Lithofacies D).

D. Tidal Flat Environment (Plate 4)

This tidal flat environment is closely associated with the lagoonal environment. Its deposits are exposed at low tide and tend to contain more sand. They are composed mainly of interlaminated thin shale, silt and very fine sand layers; carbonaceous laminae may also be present. Ripple drift cross-laminations may be present, where not destroyed by burrows. Tidal flats may develop either behind barrier bars or along low-energy coasts bordering shallow seas. Evaporite may be present. When tidal flats become supratidal, supersaline waters may occupy the available pore space and deposit evaporites. (Michealis and Dixon, Lithofacies B).

E. Interdistributary Deposits (Plate 5)

The main features of the interdistributary deposits are organic rich clays, silts and coals. Plant fragments and root marks are abundant. The rate of detritus deposition largely determines how rich the deposit may be in organic material. Coal develops when the detritus influx is low and carbonaceous shales occur when the influx is high. Rootlet horizons may be present. Interdistributary deposits are highly burrowed. Intensive burrowing can result in apparently homogeneous rock and burrows may be difficult to recognize. Coals have been found interbedded with sand showing tidal flat characteristics. Such associations are common since the two environments occur in close proximity to each other (Michaelis and Dixon, Lithofacies C).

II. Interpretation of Environments

The interpretation of environments has been indicated at the right hand side of each of Figures 9 through 16. As has been pointed out, few sedimentary structures are restricted to a single environment and any particular environment can be recognized only by a combination or a specific sequence or association of structures. The paleotopographic setting should also be taken into consideration when making a final interpretation. Findings from the eight wells have been compared with the possible arial configurations. portrayed on Map 4.

When the wells located in 11-11-73-13 W5M and in 2-21-73-13 W5M are compared, a number of similarities stand out: A series of alternating channel and lagoonal deposits overlie the Cambrian (Eldon Formation?) strata in both wells. These changes in sedimentary environments can be indicative of migrating channels and changes in the transport capacity of the stream which has delivered the sediments in this area.

The lagoonal facies is more prevalent in the 2-21 well than in the 11-11 well. This indicates that the former well was located farther from the local centre of deposition. Maps 3 and 4 place the 2-21 well near the edge of a delta formed by a small stream. This small stream entered the basin from the north, while the 11-11 well is situated closer to the main part of the delta.

The 10-5-65-23 W5M and the 4-4-66-24 W5M wells are also similar and resemble the 11-11-73-13 W5M and 2-21-73-13 W5M wells. An alternating sequence of channel and lagoonal deposits appears to overlie the Cambrian strata. The main difference between the 10-5 and the 4-4 wells is the upper core of the 4-4 well, which consists almost entirely of argillaceous sandstone and sandy shale, heavily bioturbated in the upper part. One could perhaps arrive at an incorrect conclusion that the environment of deposition of these two wells was the same as the first two wells, when the paleogeographical interpretation of either set of wells is not taken into account. The 4-4 and 10-5 wells are probably associated with a bar-like deposit. This "bar" is connected to one of the main channels and a deltalobe may well have existed in the 4-4 and 10-5 locations in early Watt Mountain deposition (Core #3, 4-4-66-24 W5M well and basal part of the 10-5-65-23 W5M well). The deltalobe has been gradually abandoned and modified by the encroaching lagoon. The sand fraction of the top section of the 4-4 well may have been derived from reworked delta deposits. The 10-5 well has remained somewhat longer under the influence of a fluvial regime but in the end a lagoonal environment prevailed. The S.P. log responses of the 4-4 and 10-5 wells differ from those of the 11-11 and 2-21 wells in that the latter two wells display a "box" type curve, which indicates that the grain size changes rapidly near the top of the main sand bodies. A "bell" shape is evident for the 4-4 and 10-5 wells suggesting a more gradual change in grain size.

The 5-35-62-18 W5M well contains a sequence of channel-like deposits, followed by tidal flat sediments. The lower boundary of the sandstone is sharp while the change to tidal flat sediments is gradual. In view of this change and in view of the S.P. curve, the well has been positioned in a deltalobe environment; on Map 4, the 5-35 well is located just next to the mouth of a major delta distributary. In this case the well is located between the distributary and a sand bar which covers the Simonette-Kaybob Ridge. The area may have been occupied by a channel draining a lagoon to the west and northwest. The S.P. curve shows a "box" shape, indicative of a channel deposit, of which the top gradually moves over to the "shale line". During early Watt Mountain deposition the location 5-35-62-18 W5M was in the reach of a distributary channel which, after some time may have abandoned its course. A renewed influx of coarser material took place but this appears to have had a short-lived effect. The well indicated that the coarse grained bed is thin, fining rapidly into a fine grained sandstone with shale streaks and flaser and lenticular bedding. This may also indicated a tidal regime; the presence of glauconite points to marine influences. The interpretation in this study is that the 5-35 well was part of a distributary mouth bar.

The 4-7-74-9 W5M well represents one of the easternmost locations included in this study. In this well, the Watt Mountain shows an environment ranging between fluvial and marine. The base consists of a coarsening-upwards sequence or delta front, which grades into a deltaic succession of channel deposits which gradually gives way to a lagoonal facies. Beach bar type sediments, with minor low angle cross-bedding follow, and these gradually change into lagoonal and beach bar environments. The top of the Watt Mountain Formation shows the characteristics of tidal flat deposists. The base of the Gilwood Member is a marine dominated delta front, overlain by a fluvial distributary channel, followed by a sequence of marginal marine beach bars and tidals flats. This mixture of marine and fluvial deposits is located next to the mouth of a small river which existed during the early stages of the Watt Mountain deposition, when the effects of the uplift of the hinterland were strongest.

The 7-7-57-12 W5M well is a good example of a beach bar succession. The basal part of the Watt Mountain Formation contains a coarsening-upwards cycle, typical of a marine environment. Three bars have been distinguished, with interspersed shallow marine deposits. The top of the core may indicate a tidal flat environment. On Map 4 the location of the 7-7 well represents an offshore bar near the eastern edge of the area of sand deposition.

The 2-25-50-14 W5M well indicates that the Gilwood forms a part of a small delta, associated with a stream which occupied a fault bounded (?) valley. The bottom of the core of the well contains some high angle cross-bedding, indicative of channel deposits. Other structures in the core indicate a beach bar type environment with restricted fluvial influences. The rest of the core suggests an alternation of beach bar and tidal flat deposits.

III. Sedimentological History and Sedimentology of the Gilwood Member

A. The Mineralogical Evidence of Source Areas and Climate

1. Source Areas of Quartz and Feldspar

The Gilwood sandstone becomes more mature towards the east. The ratios of quartz versus feldspar, monocrystalline quartz versus polycrystalline quartz and non-undulose quartz versus undulose quartz all increase toward the east and southeast. Blatt, Middleton and Murray (1972) report that the volume percentage of quartz in unweathered first cycle sediments from massive plutonic rocks averages 25%. 85% of these quartz grains display undulatory extinction. Volcanic rocks are a common source for non-undulose quartz. The same authors also note the following:

(a) The decomposition of granitoid rocks in a desert climate releases subequal amounts of mono- and polycrystalline quartz.

(b) Gneisses release 20-25% monocrystalline quartz under the same circumstances.

(c) 40% of the quartz derived from schists is monocrystalline.

(d) The quartz from these three rock types shows the effects of strain, as expressed by undulatory quartz.

(e) The amount of polycrystalline and undulatory quartz decreases with increasing transport distance. As a result, the relative amount of monocrystalline non-undulose quartz increases.

The abundance of polycrystalline and undulose quartz especially in the northwest, indicates that the Gilwood is an immature sandstone. It also indicates a source consisting of plutonic and metamorphic rocks. The Peace River Arch which is located to the north and northwest of the study area, is composed of these rock types (Burwash, 1957).

The Peace River Arch forms a positive structure of the Canadian Shield and prior to the Devonian a basement saddle formed a connection between the Shield and the Arch (Green, 1958). A continental shelf environment existed to the west of the Arch. During the Lower Paleozoic the shelf reached at least as far west as the present Rocky Mountain Trench (Monger et al, 1972). Evidence exists (see McCrossan and Glaister, 1964 and Douglas et al, 1970) that a positive area has extended to the west and northwest of the study area. A rim of Middle Devonian and part of the Upper Devonian clastic detritus has been encountered around this positive area.

The Gilwood sandstone encountered in the southern part of the Athabasca area is more mature. This may be related to either:

(a) A direct source for the sandstone which consisted of more mature, clastic deposit, or

(b) deposition under conditions which have lead to more reworking.

(a) Pugh (1971, 1973); McCrossan and Glaister (1964); Douglas (1970) and others mention the existence of the West Alberta Ridge, which borders the study area to the west and southwest. At the close of the Middle Devonian, the West Alberta Ridge was mainly composed of Cambrian sediments. The Cambrian consists mainly of carbonates, shales and siltstones, except some Lower Cambrian formations, i.e. the Basal Sandstone Unit, the Mount Whyte and the Cathedral Formations (Pugh 1973). The Mount Whyte and Cathedral formations consist of carbonate, shale and silts in outcrops to the west of the study area. They consist of coarse clastic sediments in the subsurface under the study area.

A major part of the West Alberta Ridge is buried under the overthrusts of the Rocky Mountains, but there are indications that the Cambrian on the Ridge had been extensively eroded. It is possible that Lower Cambrian and Pre-Cambrian rocks have been exposed during the late Middle Devonian. An erosional thinning to the west is indicated on the maps of Pugh (1973) for the Upper Cambrian strata especially. Price (1971) shows the sub-Devonian unconformity lying on Middle Cambrian strata at the mountain front, based on outcrops and wells drilled in the area. A closer look at cross-section by Price and Mountjoy (1970) reveals that the Cambrian strata examined are considered not to be located in their original place of deposition. The structural deformation of the Rocky Mountains should have foreshortened the Cambrian by more than 160 km. As yet, no bore holes in the Foothills belt or in the Rocky Mountains have reached below the plain of decollement. Thus all the presently encountered Cambrian rocks were originally located at an unknown distance to the west. A more severe denudation of the West Alberta Ridge by the sub-Devonian unconformity, than is indicated by various authors (e.g. Price 1971, Wheeler 1970) would be a possibility.

(b) A more distant source area lying in another direction is an alternate possibility. Various observations contradict this however, as will be explained later. A more agitated depositional environment remains as another option; it will be discussed later (Page 51).

2. Clay Minerals and Climate

The presence of certain clay minerals can be an indicator of the climate in the source area at the time of deposition. Kaolinite is one of these minerals. Kaolinite is formed mainly in tropical climates especially where lateritic soils are developed. Lateritic soils are heavily leached. Kaolinite occurs also in some podsolic soils of the temperate zone. Kaolinite is normally absent in the soils of arid climates.

The climate is not the sole factor for the formation of kaolinite. The topography is also of prime importance as it influences the rate of leaching of the soils. The presence of kaolinite in the Watt Mountain sediments may indicate a humid (?) warm climate with the possibility of seasonal rains (such as monsoons).

Another clay mineral which can be indicative of the climate in a source area is chlorite. Contrary to kaolinite, chlorite is unstable in highly leached soils. It is however, stable under normal post-depositional circumstances. Chlorite can also be the end product of the transformation of clay minerals during diagenesis. Unstable clay minerals such as montmorillomite and smectite, are subject to illitization in a K-rich environment during diagenesis; they will be transformed into chlorite in a Mg-rich environment. Many wells in the Athabasca River area contain a mixed-layer mineral of a composition, which would indicate illitechlorite or chlorite-vermiculite mixed-layer minerals. These can be formed during diagenesis and are therefore not indicative of the climate in the source areas. They can be used to reconstruct post depositional circumstances as will be explained later (Page 58).

Chlorite originates as an alteration product of ferromagnesium silicates. It is common in many igneous, metamorphic and fine grained clastic sedimentary rocks. In view of the availability of this mineral, it can be expected to be omnipresent in the Watt Mountain Formation. Chlorite, however, was found in three samples all close to the northern limit of the study area. This points to a lack of chlorite in the sediments delivered to the area, and chlorite is unstable in highly leached soils. In the source area a warm, humid (?) climate, in which leached soils prevailed, is thus a possibility.

B. The Depositional Environment

1. General Evidence from Lithologic Features and Sedimentary Structures

The overall character of the sedimentation of the Gilwood Sandstone, especially the thin sequences (cycles) encountered in all wells in the area, indicates rapidly changing transport capacities of the water in which the Gilwood was deposited. The combination of sedimentary structures as found in the study area implies a fluviatile and transitional-marine environment. Many of the observed features are not characteristic of meandering streams. The grain size variations, both vertical and presumably horizontal, are rapid and extreme. Scour and fill structures and irregular bedding contacts also suggest variable flow conditions and uneven depostional surfaces. Shaly rip-up clasts are common, reflecting the deposition of mud at one time and the erosion of it thereafter. Shales and silts are sparse and when these fine grained deposits occur they tend to be thin and lenticular in shape. These observations suggest braided stream deposits. Braided streams are the product of the variable run-off; a meandering stream needs a more regular, continuous discharge. Also the slope is important — braided streams normally occur on steeper slopes than meandering streams (Reineck and Sigh, 1973). The study of the sedimentary structures in the Gilwood Sandstone (Map 6 and Page 32), shows that the energy of the depositional environment diminishes in an east- southeast direction. A similar decrease in energy has been observed from bottom to top of the Gilwood Sandstone. This indicates a gradual change to another environment away from the source areas and as a function of time. The change to another environment is an expression of the change of the relief of the source area, or of a change in the base level of the erosion due to a rise in sea level, or both.

The Gilwood Sandstone, originating from igneous, metamorphic and sedimentary terrains to the north and west (the Peace River Arch and the West Alberta Ridge), was thus probably transported by means of braided streams towards a more or less quiet area in the south and east. Furthermore, the immature Gilwood Sandstone shows an increase in maturity to the south and east in a direct relation to the transport distance.

2. Specific Evidence from Mapping

Maps 2, 3 and 4 support such conclusions. Map 2 indicates a basin south and east of the Peace River Arch and the West Alberta Ridge. The slopes of the Arch and Ridge areas are fairly steep; whereas the centre of the basin is nearly flat. Maps 3 and 4 show a system of streams which may have drained the uplands. The higher concentration of these streams is located in the northwest corner of the area, where the Arch and Ridge meet. The streams follow a southeasterly direction. Downstream the channel deposits give way to bars. The stream pattern is deltaic with pronounced intra-distributary areas. The thickest sand deposits are located where the steep slopes meet the flat basin centre. The change from channel to bar configuration of the sand deposits is also located in this area.

Map 6 displays the differences in the S.P. curves throughout the study area. These also suggest a channel facies ("box" shape) in the west and north, while in the east and south the dominant log response is the "funnel" shape which indicates "coarsening upward" sequences. Typical point-bar sequences (fining-upward) occur only sporadically.

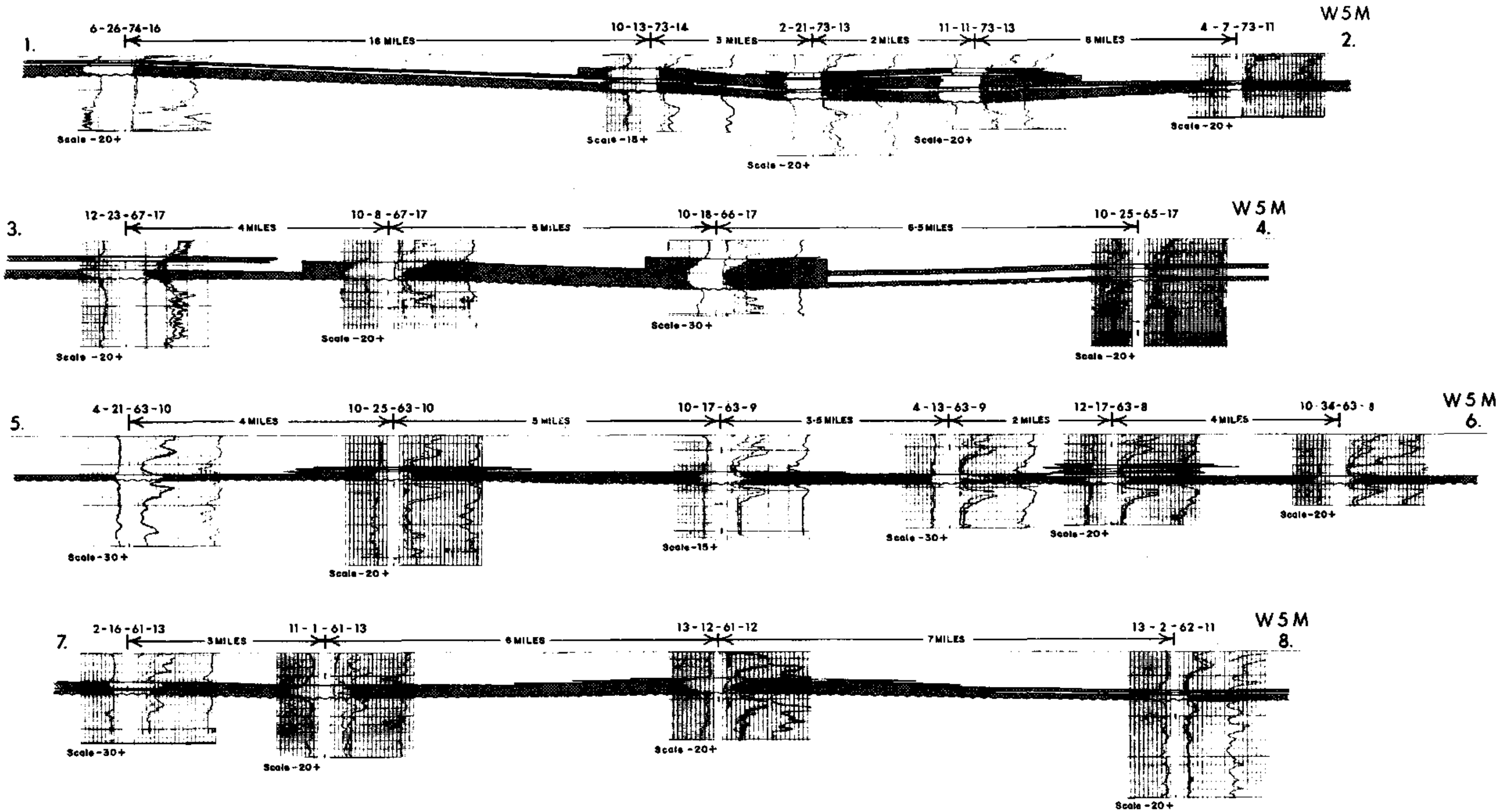
A delta front sheet sand can be recognized over most of the area. This sheet sand has been incised by distributary channels as they prograded over this sand (e.g. section 3-4, Figure 17). A stacking of sheet sands and of distributary channels has been encountered close to the source areas (Figure 17, Section 1-2). The cross-section in Figure 17 is an example of stillstands or temporary regression. A stacking of bars is noticeable on Section 5-6, Figure 17, while Section 7-8 shows a continuous bar build-up.

North of Twp. 60, the braided streams extend quite some distance into the basin. No signs of extensive reworking by the sea such as by longshore currents or wave action have been found, in spite of the fact that the supply of sediments in that area was irregular. The influence of the sea could have reached the area only from the east and south. To the east lies the Swan Hills Ridge (Map 2). The thickness and shape of the sand bodies overlying the ridge show that the ridge itself did not shed sediments; rather it had a regulating and protecting function (Maps 3 and 4). It blocked off the eastern side of the study area. The Simonette-Kaybob Ridge is present to the south (Map 2). This ridge is covered by a sand body which has been interpreted as a bar deposit. The south side is thus also more or less protected.

The situation south of Twp. 60 is different. Sand bodies seem to "hug" the topography. Typical deltaic configurations are lacking in most parts of the area. A northerly transport direction of the sediments, delivered by the stream to this area is apparent.

The configuration of the Elk Point Basin at the end of the Middle Devonian was that of an almost completely closed basin, occupying central-east Alberta and adjacent part of Saskatchewan. To the south, the Elk Point Basin was closed by the Sweetgrass Arch. Perhaps some trends such as the Meadowlark Trend were also effective barriers. To the east the Canadian Shield closed the basin. The connection with the open sea or ocean may have existed east and northeast of the Peace River Arch and the associated tidal currents may have entered the Elk Point Basin around the Peace River Arch, flowing south along its eastern slopes. This is a possibility if the direction towards the north rotating pole ("north-alignment") was roughly the same as at present. A reconstruction of the "north-alignment" has been made possible using paleomagnetism and the current model of plate tectonics.

The reconstruction has been carried out by Smith, Briden and Drewry (1973). A series of reconstructed maps of the world during the different geological periods show that the "north-alignment" for the Lower Devonian could have been the same as at present — only the latitudes and longitudes may have been different. Smith et al, have used only British data for the America-Europe plate. McElhinney and Opdyke (1973) have also reconstructed the relative position using North American data. Their results correlate with those of Smith et al. Habicht (1979) shows approximately the same picture. Paleomagnetism and plate tectonics are based on the assumption that the rotation axis of the planet Earth has not changed since the birth of the planet and that magnetism is induced by rotation. Application of Smith's maps suggest that tidal currents flowed into and out of the Athabasca River area from the north. Such tidal currents may have been kept out of the area north of Twp. 60 by the Swan Hills Ridge. The presence of this Ridge probably forced the currents on a southerly direction towards the Wilson Creek Ridge (Map 2). The Wilson Creek Ridge, a promontory of the West Alberta Ridge, may have deflected at least part of the currents in a westerly direction as some type of counter current, which followed the eastern shores of the West Alberta Ridge. This could explain the northerly deflection of sand plumes associated with a stream occupying the Stolberg and Edson Valleys (Page 18). The northwestward progression of this inferred counter current may have been impeded



ATHABASCA RIVER AREA

STRATIGRAPHIC CROSS SECTION

DATUM TOP WATT MOUNTAIN FM.

FIGURE 17

by such obstacles as the Niton Ridge and the Simonette-Kaybob Ridge. It may have been forced into an easterly direction, rejoining the main currents south of the Swan Hills Ridge, thereby completing the tidal loop. At the lee side of the Niton Ridge more extensive sand bodies occur. The southern-most ones are connected with the Edson Valley. The influence of the counter currents may be deduced from a main sand body, located in an embayment protected by the Ridge. A second major sand body exists to the northwest. Deposits from a stream, entering the embayment between the Niton and Simonette-Kaybob Ridges, progressed over a moderate distance in an easterly direction. All observations point to a quiet depositional environment. The counter currents did not affect this embayment.

The presence of tidal currents entering the Elk Point Basin and the Athabasca River area along the east side of the Peace River Arch helps to explain another problem. Maps 3 and 4 show a bar deposit east of the Swan Hills Ridge stretching from Twp. 75 Rge. 6 and 7 W5M to Twp. 66 Rge. 3 and 4 W5M. This bar is presently the reservoir of the prolific Mitsue oilfield. There is no connection between this sand body and any of the streams that may have drained the Peace River Arch toward the Athabasca area. The Nipisi and Utikuma oilfields which produce also from the Gilwood Member occur to the northwest of the Mitsue field, along the same strike and slightly "en echelon".

C. Reconstruction of Transport System in Relation to Environment of Deposition

The following reconstruction can be made:

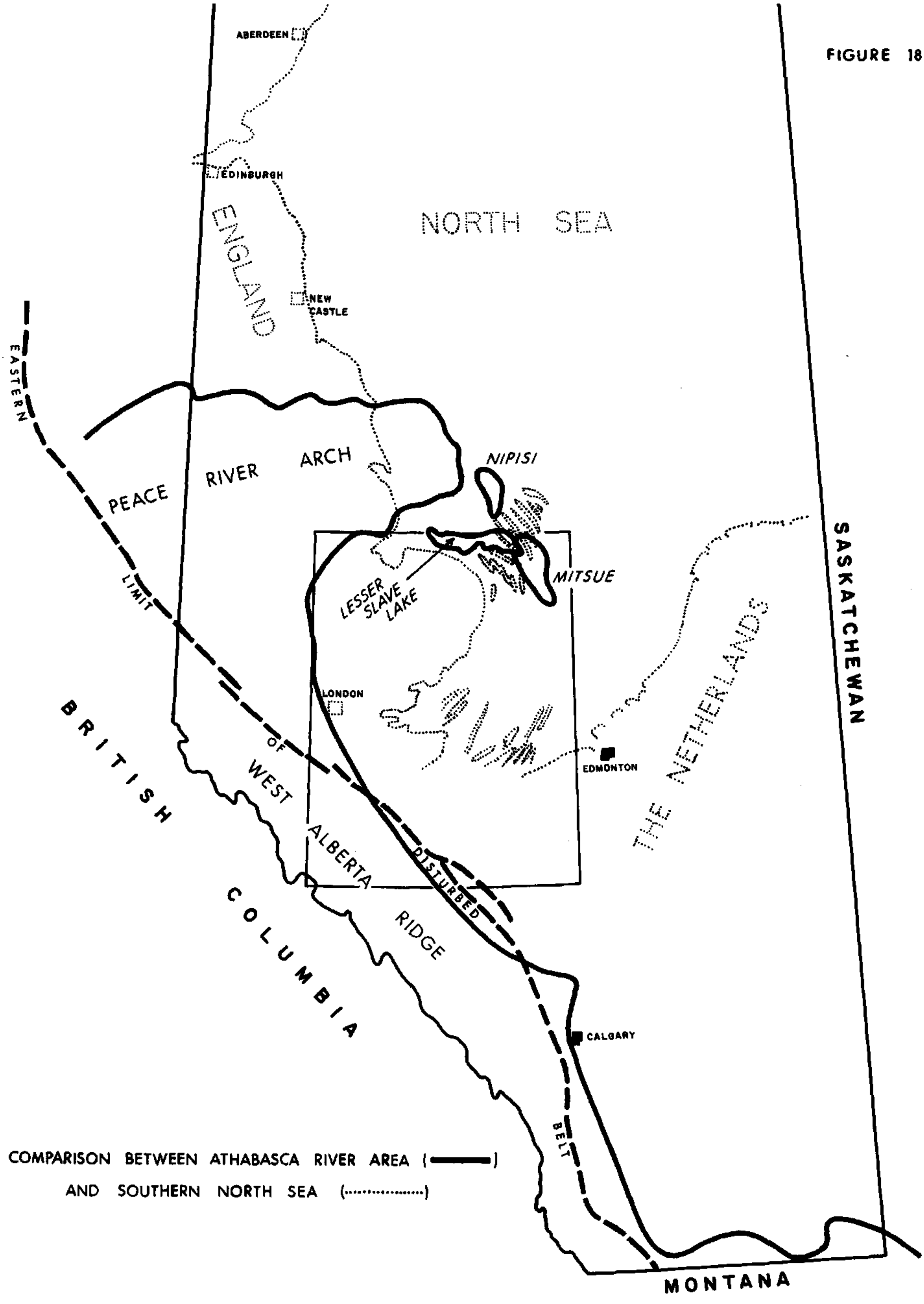
North and northwest of the Arch a thick sequence of coarse clastic material has been deposited, with a maximum thickness of over 50 m. in the Manning area of northwestern Alberta (Twp. 94, Rge. 1 W6M). In contrast, to the east of the Arch, from approximately Twp. 90 in the north to Twp. 79 in the south, only sporadic occurrences of Gilwood sandstone have been found. Nevertheless, the Watt Mountain Shales have been encountered in many wells drilled in the area. It is unlikely that no coarse clastic sediments have been delivered to the east of the Arch. It is believed therefore that tidal (?) currents may have transported this sediment southward and deposited part or all of it as the so-called Nipisi-Mitsue trend. The sandstones in the Nipisi area are slightly less mature than those in the Mitsue area (Kramers and Lerbekmo, 1967), which would suggest a north-south transport direction of the sediment. In addition, the results from the present study suggest a comparison between the Elk Point Basin and the North Sea. Tidal currents, enter the North Sea from the north around a protecting land mass. The North Sea Basin is closed in virtually all directions except to the north. The North Sea "north alignment" appears roughly the same as for the Athabasca area (Figure 18).

In the North Sea, one type of northwest-southeast trending sand ridges (Houbolt, 1968) is formed by tidal currents. This particular type of sand ridge is long and linear, subparallel to the tidal current direction and is formed on a virtually flat shelf sea bottom.

The sand ridges are mainly assymetrical in shape and the sand grains are thought to move up the gentle slope. The sand is deposited on the leeside as steeply dipping foreset beds. A vertical sequence has not been established by Houbolt, but he suggests a coarser grained "lag deposit" over-lying the older deposits, and succeeded by a wellsorted sand with distinct cross-bedding, a few shales and thin clay laminae. The sand is derived from older deposits in the area.

East and southeast of the Peace River Arch no major amounts of sand may have been available on the pre-Watt Mountain unconformity. No sand deposits connected to a river system are known along the east side of the Peace River Arch, south of Twp. 90, except for a smaller delta in the Utikuma area described by Shawa (1969). Large amounts of coarse clastics may not have come from the west either; the present study shows that no major river system, which could have provided the amount of sediment south of Twp. 76, could have entered the basin east of the Swan Hills Ridge. North of Twp. 75, the literature does not indicate a major river either, except a smaller delta in the Utikuma Lake area (Shawa, 1969).

In his Utikuma study, Shawa has discovered a typical deltaic sequence from shallow marine through fluvial-transitional to fluvial in both horizontal and vertical direction. He also mentions the action of longshore currents.



COMPARISON BETWEEN ATHABASCA RIVER AREA (▬▬▬)
AND SOUTHERN NORTH SEA (··············)

The eastern slopes of the Peace River Arch north of Twp. 80 show some depressions, trending in a west-east direction (Pugh 1973, Fig. 11). These depressions could have been valleys through which streams drained the Arch to the east. The Gilwood Sandstone has rarely been found to the east of the Arch possibly in some remnants of a series of beach-bars. A transgressing sea during the early Franian could have destroyed most of such existing sandbars. There are not many wells in the area where the ancient Watt Mountain shoreline is assumed to have existed (Twp. 80, Rge. 10 W5M through Twp. 88, Rge. 14 W5M).

Pugh (1973) has assigned the sediments, filling some deep valleys on the slopes of the Peace River Arch to the Keg River Formation. On the other hand, a normal onlap sequence may have existed along the west and north side of the Elk Point Basin. This onlap sequence is suggested by evidence shown on Map 1, where a fence diagram shows the relationship between the Watt Mountian Formation and the pre-Watt Mountain Formations.

A distant source area is unlikely for the sediments in the area south of Twp. 60. The inferred tidal currents prescribe an east-southeasterly source. The Watt Mountain formation becomes more and more argillaceous in an east-southeasterly direction. As yet, there is no evidence of a possibility of a major supply avenue in the area. The wells drilled in the area show shale and siltstone and in some cases a few feet of sandstone (e.g. 9-23-40-9 W5M). Furthermore, the sand transported by currents from the eastern shores of the Peace River Arch towards the south reached as far south as Twp. 60. South of Twp. 60 no sand has been found in wells east of a line from Twp. 61 Rge. 5 W5M to Twp. 40 Rge. 19 W5M. It is not plausible that a current transports large quantitites of sand without leaving a trace.

Red (brown) and green shales are an indication of an oxidizing and a reducing environment, respectively. The red (brown) colour can be produced by oxidation of detrital iron oxide which leaves a coating of hematite pigment around the rock particles. This can happen in soil zones in many climates.

Red (brown) coloured shales occur predominantly in the northwest corner of the area. This can be the result of a depressed water table which in a continental environment, resulted in the oxidation of the ferrous iron present.

Red (brown) shales are usually associated with green shale. The green colour is dominant in the Watt Mountain Formation. This leads to the interpretation that red beds are an oxidation product of green shales rather than the other way around. If the red colour was formed by soil forming processes, pedogenic features such as rootscars would be present. These features were not encountered in this study. The red colour occurs as irregular shaped patches in the green shales and the zones in which they are present cannot be correlated between wells. The red coloured beds are not very thick (maximum 30 cm.), while the horizontal extension is mostly less than the width of the core (9 cm.). It is thought here that the red colouring is due to oxidation and/or percolation of oxygen-rich water during short spans of low water tables in some lagoonal areas. The first possibility could have occurred in temporarily abandoned parts of a stream bed (e.g. 2-21-93-13 W5M and 11-11-73-13 W5M. Percolating oxygen-rich waters are more likely in wells such as: 14-31-63-8 W5M). This well is located in a barrier bar area. However, the possibility of sub-aereal exposure in a lagoonal-tidal flat regime cannot be excluded. More data appear to be necessary for a conclusive environmental description of red and green shales.

Jansa and Fischbuch (1974) indicate a soil zone in the extreme northwest corner of the area. They appear to have recognized this zone in two wells: 10-14-72-23 W5M and 10-23-71-19 W5M (Jansa and Fischbuch, 1974, Figs. 6, 12 and 13). Their findings have not been corroborated by this study. The first well has been interpreted to contain no Gilwood Sandstone, while a zone of carbonate concretions has been assigned to the lower part of the Slave Point Formation, instead of the Watt Mountain Formation. The carbonate concretion has been used by Jansa and Fischbuch as possible indicator of a soil zone.

The Gilwood Sandstone gradually fines upwards and grades into a siltstone and shale sequence with many sedimentary structures similar to those found in contemporary tidal flat areas (Reineck, 1967; Reineck and Singh, 1973). It is possible that streams gradually delivered less sediment to the Athabasca River area and that a tidal flat environment prevailed. The upper boundary of the Watt Mountain formation represents a gradual change of these tidal flat sediments to the deposits of the Fort Vermilion Formation. The Fort Vermilion Formation consists of a shale, carbonate and evaporite sequence which displays the characteristics of deposition on a board inter-tidal zone, not unlike the present day Trucial Coast environment (Jansa and

Fischbuch, 1974). The overlying carbonates of the Swan Hills Formation indicate a marine transgression. The contact is sharp in most locations. No signs of extensive re-working of Fort Vermilion sediments have been found. It can be concluded that the transgression has taken place over a short time span. Two periods of less rapid transgression or possible regression can be recognized. Map 4 shows two areas of lateral outbuilding of sand deposits on the slopes of the Peace River Arch and the West Alberta Ridge. Both areas are located in the northwestern part of the Athabasca River area. They exist at a considerable elevation above the basin bottom (Areas "A" and "B", Fig. 19). The sand bodies follow the paleotopographic contours in Area "A". The stream channels suddenly stop on the paleoslope in Area "B", far short of the basin bottom over which the main distributary channels extend.

Area "A" is interpreted here as consisting of a series of offshore bars formed during a slowdown in the sea level change. Area "B" (see Map 4), represents a temporary and local (?) regression where the streams formed small deltas, e.g. Twp. 73 Rge. 18 W5M. Much of the character of these "B" areas is obscured because of the similarity of the underlying older Watt Mountain sediment. It is mostly impossible to distinguish the older from the newer deposits. A certain reworking of older material is a possibility as is indicated by the increase in the quartz/feldspar ratio in the vertical sequence in the 9-17-73-18 W5M well.

The maximum thickness of the Watt Mountain Formation in the Athabasca River area is at present less than 30 m. Even when a significant thickness reduction due to compaction is considered, it is unlikely that the Watt Mountain shales directly underlying younger formations, preserved in the extreme northwestern and western parts of the study area are of the same age as those in the centre of the area. The Watt Mountain Formation is considered diachronous. This could explain the different ages that have been assigned to this formation by different authors (e.g. Shawa, 1969).

The relationship of Areas "B" and "A" has been shown on Fig. 19. Areas "B" and "A" are separated by approximately 50 m. of sediment; and equal vertical distance separates the main delta from Area "A" (Fig. 19). South of Twp. 55 the tidal flat-delta character is not evident. This however may be mainly due to the lack of drilling in this area.

The Fort Vermilion Formation overlies the Watt Mountain Formation east of the West Alberta Ridge and south of the Peace River Arch in the Athabasca River area. For example, Fig. 19 shows that Area "B" near the West Alberta Ridge is not overlain by the Fort Vermilion Formation. The sediments of the Fort Vermilion Formation are thought to have been deposited in an intertidal to supratidal environment. This range of environments has been compared with the Trucail Coast type environments (Jansa and Fischbuch, 1974). The existence of Mg-rich percolating waters is implied by the following observations: Since an Mg-rich environment is needed for the chloritization (Dunoyer de Segonzac, 1970), and since a mixed-layer mineral of a possible illite-chlorite-vermiculite composition has been encountered in shale samples, it is believed that the mixed-layer minerals are the result of the effects of the Mg-rich waters on the clay minerals during diagenesis.

A climate for the Athabasca River area at the end of the Middle Devonian has been inferred from the following observations. The clay mineralogy suggests a possibily humid warm climate in the cource area (Peace River Arch, West Alberta Ridge). The braided streams indicate intermittent run-off. The Fort Vermilion deposits resemble sabkha sediments in a semi-arid climate. The Peace River Arch and West Alberta Ridge could have been of low relief during the final part of the Muskeg deposition. A thick sequence of shales, carbonates and evaporites has been deposited instead. The climate during this time is thought to have been semi-arid (Jansa and Fischbuch, 1974), althought a more humid climate could have existed as well. It is known that a number of present day tropical rivers carry smaller amounts of coarse clastic sediment, because the chemical erosion in the hinterland is severe. Littoral and terrestrial sediments of the Upper Muskeg may have been removed during the Late Givetian erosion. This would result in a sequence with a deficiency in coarse sediment. The Peace River Arch and the West Alberta Ridge likely could have been covered by a thick, heavily leached soil zone. These soils, actively eroded during the Watt Mountain interval as a result of a change in sea level, produced kaolinite. Kaolinite prevailed in the sediment load of streams draining the Arch and Ridge. Chlorite was lacking due to leaching of soils.

The uplands of the Arch and Ridge may have received precipitation intermittantly, if the Canadian Sheld was located in the topical to subtropical climate belts north of the equator (Smith et al, 1973). The Peace River Arch and West Alberta Ridge may have formed on offshore island or group of islands to the

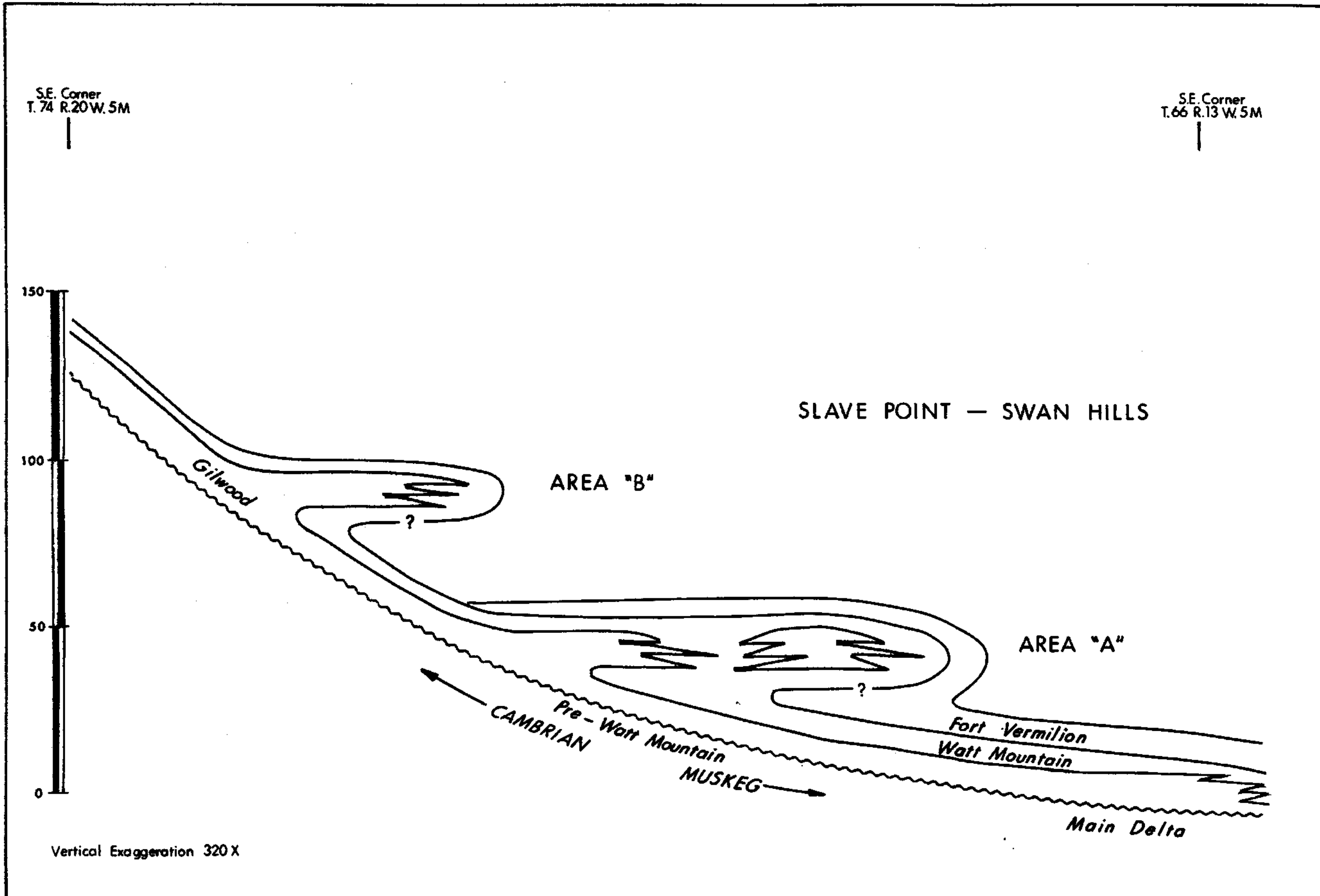


FIG - 19 SCHEMATIC CROSS SECTION ILLUSTRATING THE VERTICAL RELATIONSHIP BETWEEN AREAS "B", "A" & THE MAIN GILWOOD SAND DEPOSITS.

southwest of the Shield. Rainy periods of the monsoon-type could have occurred during a part of the year. During the rest of the year, a northeast trade wind may have been responsible for a dry climate if the air came directly from the Shield area and if the passage over open water was too short to humidify the air.

The above discussion can account for the clay mineralogy, the intermittant run-off, and the dry spells with sabkha sediments. Jansa and Fishcbuch (1974, Fig. 41) also discuss the existence of northeast winds.

General Synthesis

The Peace River Arch and the West Alberta Ridge were reactivated at the close of the Middle Devonian. The renewed relief forced rivers to incise into their valley floors. A sudden influx of coarse clastic material resulted and was felt throughout the western part of the Elk Point Basin (Gilwood Sandstone) and also the north of the Peace River Arch (Manning Sandstone Member, Rottenfusser 1974).

A complex of deltaic sand bodies were formed along the eastern shore of the West Alberta Ridge and the southern shore of the Peace River Arch. These sandstone deposits are best developed in the quiet lagoonal area in the northwestern part of the Athabasca River area. A rapid building-out onto the pre-Watt Mountain strata did not allow for the deposition of shales and silts at the base of the Watt Mountain Formation close to the source areas; the Gilwood Sandstone overlies the older, Cambrian or Muskeg strata with erosional contact. Less than 30 cm. of shale can be encountered in some locations. In the vicinity and south of the Swan Hills Ridge, a normal deltaic shale to sand sequence is prominent.

Distributary channel and intradistributary channel environments surround the basin edge as a "halo", approximately 80 km. wide. The area between this "halo" and the Swan Hills Ridge consists of distributary mouth bars and barrier bars. Very little or no sand was deposited on the Swan Hills Ridge while east of the Ridge, a system of barrier bars runs in a north-northwest to south-southeast direction.

Only a few deltaic deposits are found south of Twp. 60. Distributary channel and interdistributary channel environments developed only in protected bays and submerged valleys. The open sea was too agitated to allow for the occurrence of these environments. Beach bars and offshore bars were formed instead. Strong currents probably moved the sediments northward along the coast.The width of these zones of deposition amounts to 25 km.

Tradewinds did come from the north, causing a more severe erosion at the north side of the emerging landmass; meanwhile, the southern part of the Peace River Arch was under the influence of less humid conditions. A similar situation can presently be found on the Hawaiian Islands, where the southwest coasts of the islands are drier than the northeast sides. Since the Peace River Arch, at the end of the Givetian, was considerably bigger than an Hawaiian Island (150 km. vs. 40 km.), the climate differences would have been more pronounced. The rivers, draining the Arch to the south originated in areas with high rainfall and consequently deep chemical erosion. Reineck and Singh (1973) note that braided streams are more indicative of the steepness of the slope, than the amount of precipitation. Thus, under the same climatic conditions, braided streams will be formed in steeper terrains, while meanders will develop where the terrain becomes a more graded country.

Such a tropical climate is suggested by the clay mineralogy. The relief of the source area became subdued by the close of the Watt Mountain deposition. Intertidal and supratidal sediments of the Fort Vermilion Formation were deposited as a consequence. Associated with a reduction of the amount of new sediment delivered to the basin in this area, a new era of transgression may have started. The sea probably encroached on the Peace River Arch and the West Alberta Ridge. The rise of the sea level led to a minimal reworking of the sediments, which indicates that the change in sea level was rapid. Two periods of less rapid subsidence and/or stagnation have been distinguished (Map 4, Areas A and B).

The deposits of the Fort Vermilion Formation are conspicuously absent in Area B and occur only in isolated locations in Area A. East of Area A the Fort Vermilion Formation is almost omnipresent. This distribution pattern reflects that the Fort Vermilion is: a) not time transgressive, and b) the last stage of the regressive sequence which started with the Watt Mountain (Gilwood) deposition. A faster rising of the sea level spelled the end of the supratidal conditions and a marine environment took possession of the area. Marine carbonates of the Swan Hills Formation were deposited.

APPENDIX 1

SURVEY SYSTEM

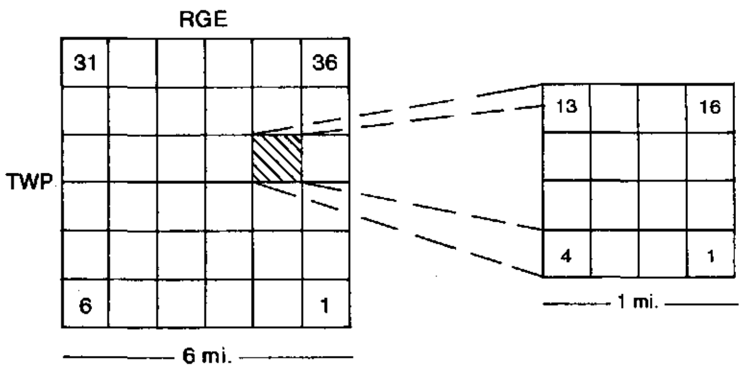
The survey system used in most of Western Canada is known as the township and range system. It is used from Winnipeg, Manitoba in the east to the Rocky Mountains in the west, and from the U.S.-Canada border in the south to the 60th parallel in the north. The purpose of the system was to provide each pioneer farmer with an equal amount of land (¼ section).

The area is divided into quadrilateral townships containing 36 sections of one mile square. These townships are bounded to the east and west by meridians while the northern and southern boundaries are parallels of latitude. Correction lines are established in the following fashion:

Control meridians exist spaced on four degree intervals west of the "primary Meridian" which lies just west of Winnipeg, Manitoba. Base lines are drawn every four townships (24 miles) based on the 49th Parallel and the control meridians.

Each of the 36 sections consists of 16 Legal Subdivisions (L.S.D.) which are 40 acres (16 ha) in size. The townships are numbered from the 49th Parallel northward; ranges are numbered from each control meridian westward.

Well locations as used in this paper (e.g. 2-21-73-13 W5M) are to be "read" as follows:



2 = L.S.D. 2
21 = Section 21
73 = Township 73
13 = Range 13
W5M = West of the 5th Control Meridian (114° W Long.)

APPENDIX 2

B. Economic Aspects

Oil from the Gilwood Member has been recovered from drill-stem tests in a few wells in the Athabasca River Area. The gravity in degrees A.P.I. was determined in only ten wells outside the Mitsue field. To complement the sparse data, the average gravity of the Mitsue field has been added as a control point. These eleven points, all occurring to the north of Twp. 60, are indicated in Figure 20. An area of low gravity borders the Peace River Arch and the West Alberta Ridge. This area covers also the Swan Hills Ridge and thus divides the region into two parts, one to the west and the other to the east of the Ridge.

A number of theories, dealing with changes in oil gravity, are mentioned in the literature. Curtis et al (1958, page 291) state that "within groups of strata of like age, a rough correlation between depth of burial and A.P.I. gravity exists". The gravity increases generally with depth. This may be true in a very general way, it does not explain, however, why. In the area of study, the gravity of the Mitsue field is much higher than in the area of the Ante Creek field (Twp. 66, Rge. 24 W5M), while the Gilwood Sandstone in the former field is at a much shallower depth (5500 feet versus 11500 feet). If it is assumed that the oil migrated prior to the collapse of the Peace River Arch during the Permo-Carboniferous, then the gravity-depth theory cited by Curtis et al (1958) seems to be more valid. The deeper parts of the Elk Point Basin were to the east and southeast of the Arch. Many questions remain to be solved: e.g. why is the gravity in the area of Giroux Lake (65-20 W5M) higher than in the southern part of the Virginia field (60-12 W5M), while the latter was located closer to the deeper part of the basin?

Stenzel (1965) described the migration of oil in the Abo Formation in the Permian Basin of Texas and New Mexico. The oil gravity profile decreases up-dip from the depositional basin towards the shelf. When the profile was established prior to a change in the direction of the regional dip, then the profile would not reflect this change.

According to this theory, the oil gravity profile of the Gilwood Member could indicate two basins in the northern part of the Athabasca River Area: one to the east of the Swan Hills Ridge, in which the Mitsue oil field is located; the other to the west of the Ridge. West of the ridge only small and widely separted oil shows are encountered. Several well logs indicate the possible presence of hydrocarbons in the area, but unfortunately these wells were not tested. It has been proven to be a necessity to carefully evaluate the logs when drilling in this area; it is known that the Gilwood Sandstone is capable of hydrocarbon production, while the resistivity of this zone is as low as 2 ohms. The available data is scant and the above sketched exploration model must be treated as preliminary, although it might be of help in the search for much needed new reserves.

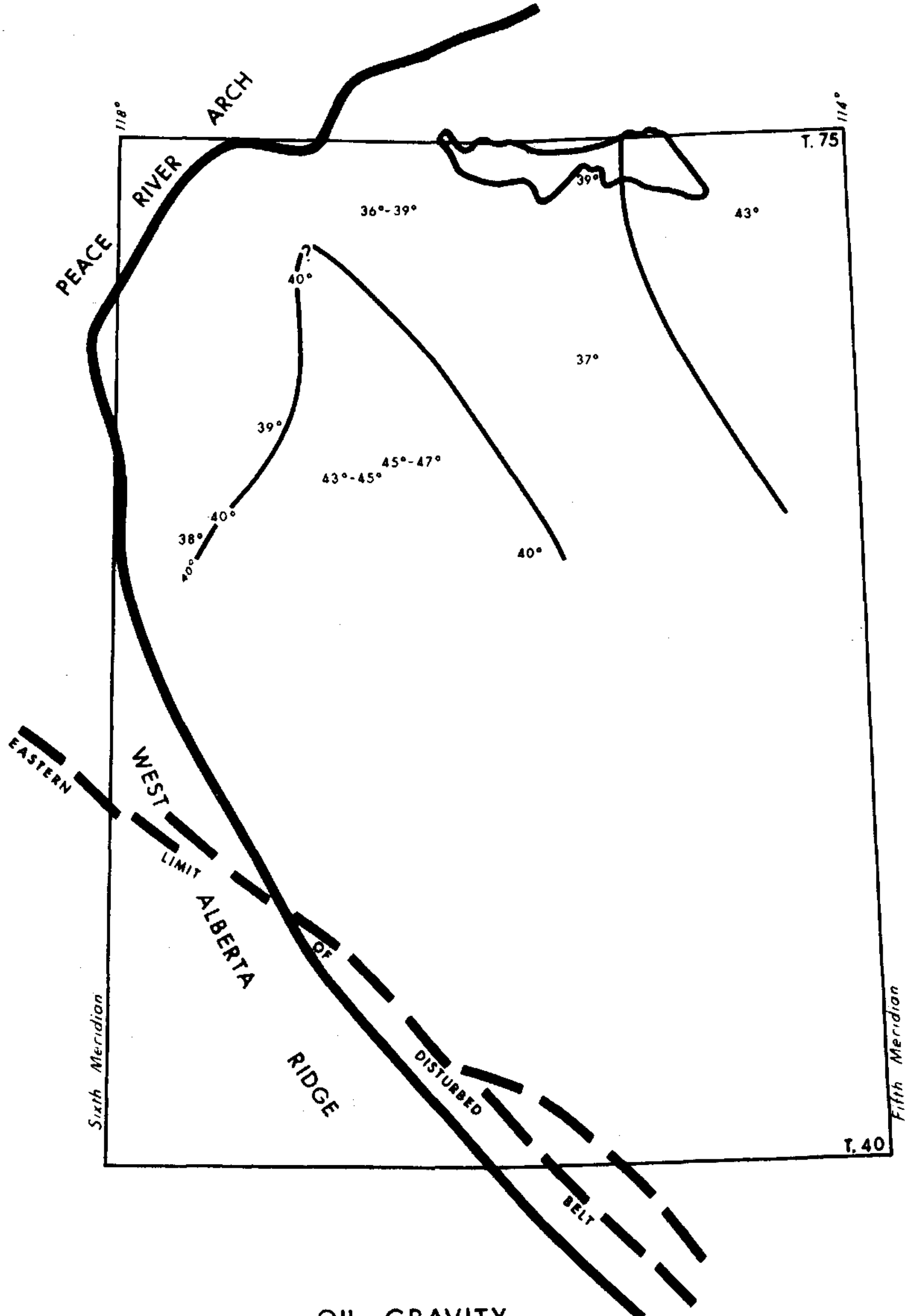
The oil gravity also indicates the existence of the Swan Hills Ridge as a positive feature during Gilwood deposition.

Areas "A" and "B" (Map 4, Fig. 19) are prospective for hydrocarbon accumulations (Busch, 1971, 1974). Apparently deposits of sand accumulated in these areas during times of stillstand or slight regression of the shoreline. The regional dip shifted from east-southeasterly to west-southwesterly during the post-Devonian (McCrossan and Glaister, 1964). Such sand bodies could have trapped hydrocarbons already present prior to the reversal of the regional dip. Any younger oil and gas may have migrated after the regional dip change. The Gilwood oilfield (73-18 W5M) can be explained with this exploration model.

APPENDIX 3

Trend "Surfaces" for Isopach, Etc.

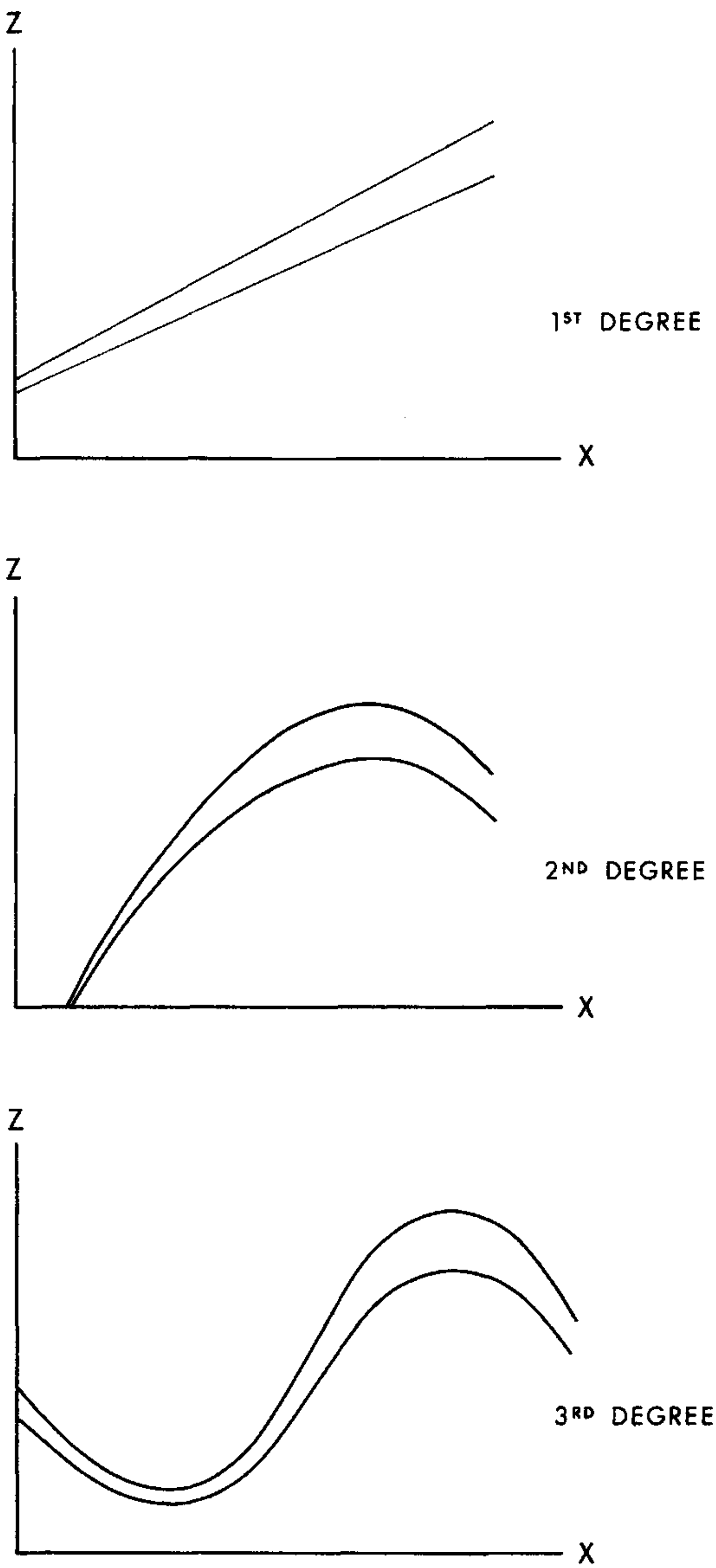
Harbaugh and Merriam's explanation (Harbaugh and Merriam, 1968) of trend surfaces is primarily applicable to trend analyses of structures. This interpretation has been applied to trend surfaces of isopachs, and isolith. The X and Y values represent the location coordinates, while the Z value represents the isopach (isolith, etc.) thickness. An isopach (isolith, etc.) value represents a thickness. Likewise a trend surface of an isopach (isolith, etc.) should be considered as a "body" which thickens when the Z values (isopach, etc. values) become higher, and thins when the Z values are lower. The first degree trend "surface" resemble a wedge, whereas the second degree surface may look like a lens, etc. Fig. 21 pictures in two dimensions some of the shapes which such "bodies" can assume. There are many ways of vizualizing these "bodies" e.g. a second degree "body" can be interpreted as convex-convex or convex-upward with either a concave or flat lower surface. The rules for isopachs as explained by Potter (1967) apply also to trend surfaces. For example the trend "surface" of Map 3 has been described as a convex-convex lens.



OIL GRAVITY

40° = 40° A.P.I. OIL GRAVITY

(Geological Outline after McCrossan and Glaister, 1964, Fig. 6-2)
SCALE = 1: 2,000,000



TREND "SURFACES" FOR ISOPACH, ETC.

APPENDIX 4

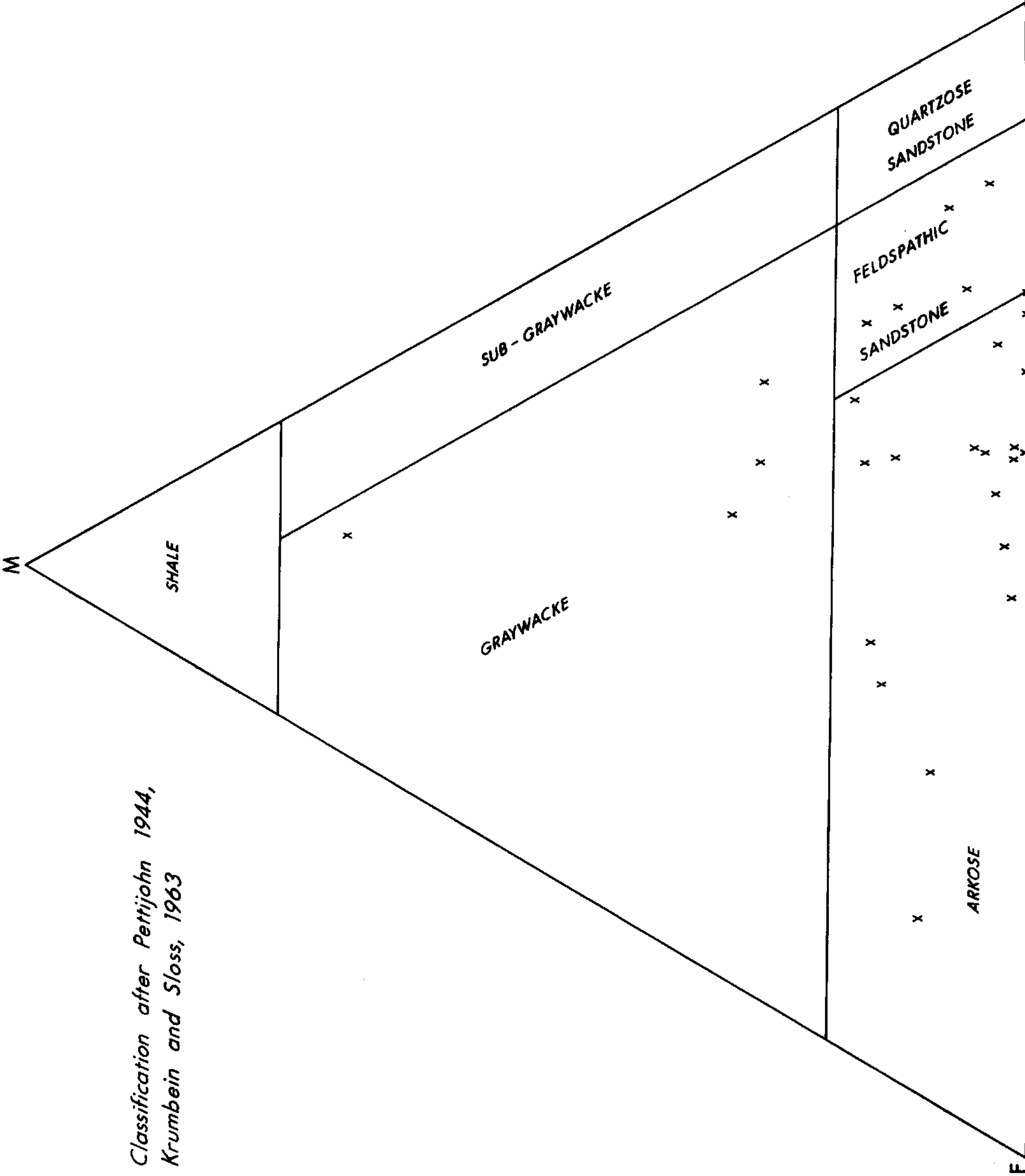
Well Number	Well Location	Sample Number & Depth		Temperature @ Bottomhole (°F)	Form Water Salinity (ppm)	Minerology
1	4- 7-68- 7 W5M	3	7379			I(t); I-M(11.0)(p)
		4	7376	165° @ 8130	175,000	I(a); K(a): I-M(p)
		5	7401			I(a)
2	2-27-71-12- W5M	9	7370	Not Determined	200,000	I(m); I-M(11.0)(p)
3	4- 7-74- 9 W5M	12	6078	122° @ 6352	150,000	I(m); K(m); I-M(11.2)(p); F(p)
4	4-34-67-18 W5M	17	9252	195° @ 9369	280,000	I(m); I-M(p); F(p)
5	8-26-69-13 W5M	20	8484	162° @ 8515	Not Determined	I(p); F(p)
6	10-13-68-16 W5M	23	9223	178° @ 9250	250,000	I(a); I-M(11.7)(p); F(p)
		24	9228			I(a); I-M(10.8)(p); F(p)
7	4-14-70-15 W5M	31	8287	149° @ 8324	265,000	I(a); I-M(11.0)(p); M-L(t)
		32	8262			I(a); I-M(p); F(p); M-L(t)
8	11-11-73-13 W5M	34	7018	134° @ 7385	Not Determined	I(a); I-M(10.5)(p); M-L (Vermiculite?)(t)
		36	7043			I(m); I-M(11.0)(p); K(m); H(t); Chlorite(p); M-L(t)
9	11-18-72-12 W5M	39	8203	164° @ 8542	Not Determined	I(a); I-M(10.5)(p); K(p)
10	12- 6-72-18 W5M	46	8722	145° @ 8765	260,000	I(a); I-M(10.5);, 11.0)(p); K(m); F(t)
11	9-17-73-18 W5M	58	8110	150° @ 8327	Not Determined	I-M(10.5;11.0)(a); I(m); M-L(Illite-Chl?)(p)
12	2- 4-74-18 W5M	60	7845	Not Determined	270,000	I-M(10.5;11.0)(a); I(m); K(p); F(p); Chl(t)
13	10-26-59- 9 W5M	62	8075	196° @ 8585	200,000	I(a); I-M(10.3)(p); M-L(p)
		64	8098			I(a); I-M(10.2;11.0)(p); F(m)
14	10-33-62-23 W5M	67	11760	200° @ 11809	185,000	I(a); I-M(10.3;11.0)(p); F(m)
		68	11763			I(a); I-M(10.4;11.3)(p); M-L(p)
15	4-13-63- 9 W5M	69	8030	179° @ 8849	Not Determined	I(p); I-M(p)
16	10-31-63- 7 W5M	72	7459	190° @ 8203	Not Determined	I(a); I-M(10.4; 11.0)(p); F(t); M-L(p)
17	4-18-64- 9 W5M	74	8400	162° @ 8424	160,000	I(a); I-M(10.4; 11.0)(p); F(t); M-L(p)
18	10-17-64-13 W5M	75	10074	195° @ 10683	Not Determined	I(m); I-M(10.5)(p); F(m)
19	14-31-63- 8 W5M	77	7924	188° @ 8681	Not Determined	I(m); I-M(9.9)(p)
20	4- 4-66-24 W5M	87	11590	192° @ 11781	250,000	Q(m); I(m); I-M(10.2)(p)
21	5-35-62-18 W5M	90	10219	Not Determined	Not Determined	I(p); I-M(10.5)(t)
		93	10241			I(m); I-M(10.7)(p); F(m)
		94	10285(Cambrian)			I(m); I-M(10.6)(p); F(p); M-L(p)
		97	10298(Cambrian)			Q(a); F(a); I(p)
22	7- 7-57-12 W5M	110	9697	190° @ 9762	110,000	I(10.3)(a); M-L(p)
23	4-22-45- 5 W5M	115	10349	200° @ 10365	Not Determined	Anhydrite
24	10-15-56-11 W5M	117	9508	184° @ 10400	Not Determined	I(10.2)(a); I-M(10.5;11.5)(p); M-L(p)
		110	9528			I(10.1)(a); I-M(10.7)(p); M-L(p)
		122	9535			I(a); I-M(11.0)(p); M-L(p)
25	2- 6-47- 4 W5M	126	9479	Not Determined	Not Determined	I(a); I-M(10.3;11.0)(p); F(m); M-L(p)
26	2-25-50-14 W5M	128	11755	240° @ 11912	Not Determined	I(10.0)(a); I-M(10.2;11.0)(p); M-L(p)
27	10-28-52-16 W5M	130	11885	190° @ 11978	180,000	I(10.0)(a); I-M(10.5)(p); M-L(p); F(p)
28	1-32-56-19 W5M	132	13333	210° @ 13727	Not Determined	I(10.9)(a); I-M(10.4)(p); M-L(p); F(t)
		136	13343			I(10.1)(a); I-M(10.5)(p); M-L(p); F(t)
29	6-15-58-17 W5M	138	11708	190° @ 11755	Not Determined	I(10.2)(a); I-M(10.6)(p); M-L(p); F(t)
30	15-29-55-17 W5M	142	11986	240° @ 12940	Not Determined	I(10.1)(a); I-M(10.5)(p); M-L(p)
31	10-12-58-13 W5M	145	9383	176° @ 9470	Not Determined	I(a); I-M(10.5;11.8)(p)
		149	9390			I(a); I-M(10.4)(p); F(t)
		151	9392			I(a); I-M(10.4)(p); F(p); M-L(p); Chl(?)(t)
		152	9395			I(a); I-M(10.5)(p); F(t); M-L(t)
32	10-11-53-14 W5M	155	10905	207° @ 11697	Not Determined	I(a); I-M(10.3;11.5)(p); F(m); M-L(p)
		156	10913			I(a); I-M(10.2;11.7)(p); F(p)
		158	10918			I(a); I-M(10.5)(p); F(p); M-L(p)
		162	10923			I(a); I-M(10.5)(p); F(p); M-L(p)

LEGEND

I	Illite		
I-M	Mixed-Layer (Illite-montmorillonite)	H	Hematite
M-L	Mixed layer (exact composition not determined)	(a)	greater than 25%
F	Feldspar (intermediary microcline)	(m)	10-25%
Q	Quartz	(p)	2-10%
Chl	Chlorite	(t)	smaller than 2%
K	Kaolinite or metahalloysite	10.5	(mid point of broad peak)

APPENDIX 5

Figure



Classification after Pettijohn 1944,
Krumbein and Sloss, 1963

APPENDIX 6

Determination of Formation Water Salinity from Well Logs

The following steps were taken to determine the salinity of formation waters:

A) The porosity was obtained from the sonic log.

B) The resistivity log provided the Rt (true resistivity).

C) Chart SW-9 (Schlumberger, 1972[B]) was used to obtain the Rwa value.

D) The Rwa value was converted to Rw and salinity with the help of Chart Gen-9, A-6 (ibid).

Example:

Porosity = 18%
Rt = 3 ohms
(Chart SW-9) Rwa = 0.120
(Chart Gen-9) Rw = 0.235; Salinity = 40,000 ppm.

Reference:

Schlumberger, 1972[B], Log Interpretation Charts: New York, N.Y. 92 p.

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SAMENVATTING

De Gilwood Member van de Watt Mountain Formatie (Givetien) in het Athabasca River gebied van Midden-Alberta, Canada, bestaat overwegend uit een deltaische afzetting, die de, boven water uitstekende, Peace River Arch en West Alberta Ridge omzoomde. De paleogeografie van het sedimentatie gebied is verkregen met behulp van paleotopografische reconstructie methoden, van trend analyse aan de Gilwood zand-isolith en van een gedetailleerde analyse van boringen. Het milieu van afzetting in het noordelijk deel van het gebied werd beinvloed door een systeem van, zich onder water bevindende, ruggen, die straalsgewijs uitliepen van de Peace River Arch en de West Alberta Ridge. Deze ruggen sloten een lagune af, die zich ten Noorden van Twp. 60 en ten Westen van Rge. 10 W5M. bevond. In deze lagune werd een 20 meter dik deltaisch complex afgezet, over een ondergrond, gevormd door Cambrische en Midden-Devonische gesteenten. In het oostelijk gedeelte van de lagune werden minder grofkorrelige sedimenten gevormd. Buiten deze lagune was de vorming van delta's onmogelijk door het hoger energetische open marine milieu. Getijdestromen, die van het Noorden af het Elk Point Bekken binnen kwamen, zetten het meegevoerde sediment in de vorm van zandbanken af, die nu de Nipisi en Mitsue olievelden vormen (Twp. 77-81, 7-10 W5M. en Twp. 68-73, Rge. 3-6 W5M., respectivelijk). Een noordelijke tegenstroom ontstond in het gebied ten Zuiden van Twp. 60. Deze tegenstroom transporteerde het voorhandene sediment en zette het af in de vorm van zandbanken voor de kust.

Gegevens uit het onderzoek van boorkernen en van slijpplaatjes maakten duidelijk dat de Gilwood zandsteen uit twee verschillende gebieden afkomstig is, n.l. de Peace River Arch en de West Alberta Ridge. De Peace River Arch bestond uit metamorfe en stollingsgesteenten; de West Alberta Ridge, daarentegen, uit niet-metamorfe (Cambrische) sedimentgesteenten. Tijdens de afzetting van de sedimenten van de Watt Mountain Formatie, was het klimaat tropisch. Daardoor werden de landgebieden sterk chemisch verweerd en was de verweerde bodem aan uitloging onderhevig.

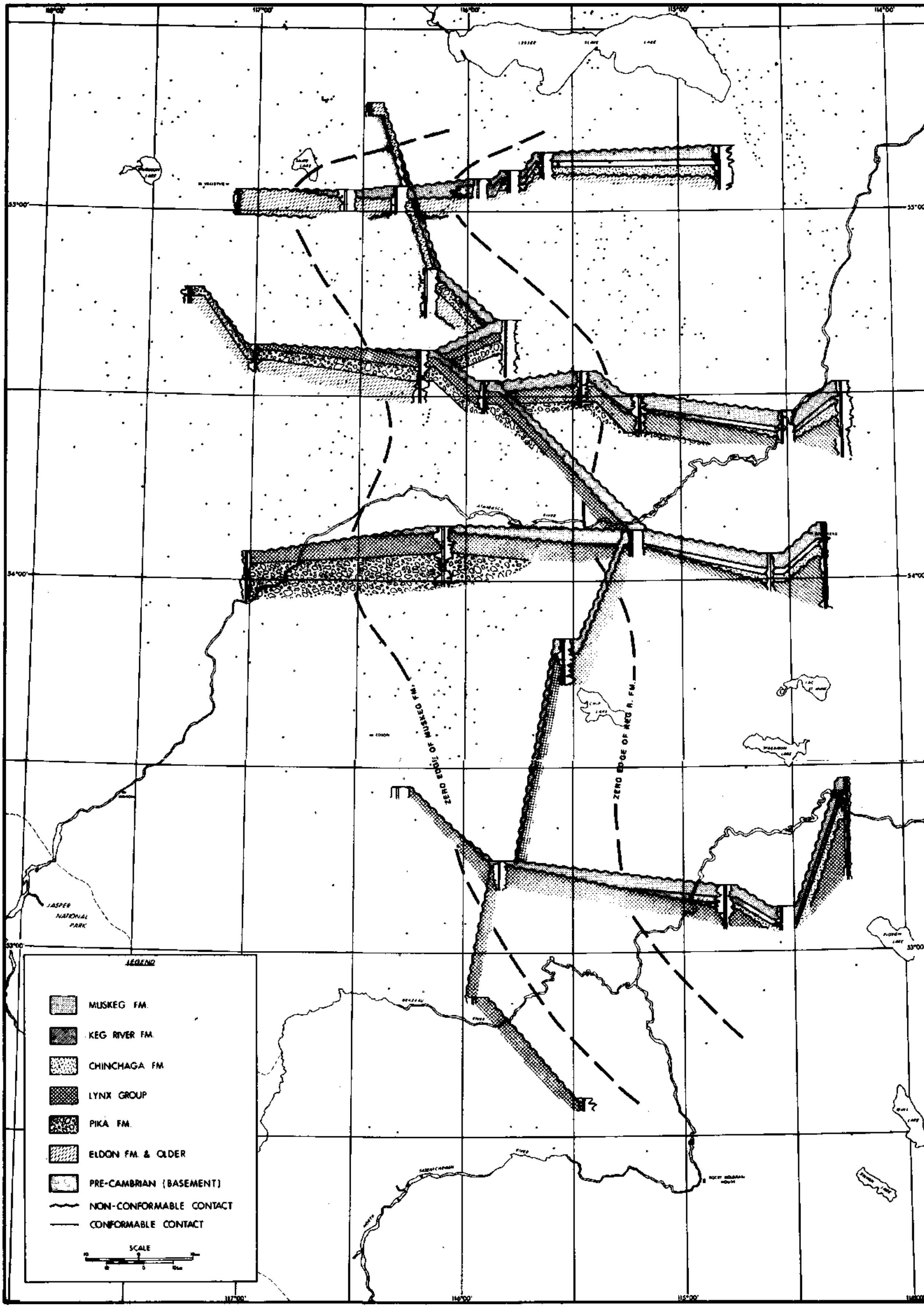
De afzetting van grofkorrelig klastisch sediment kwam tot een einde door de denudatie van het oorspongsgebied. De hieropvolgende transgressie werd door twee perioden van stilstand, of gedeeltelijke regressie, onderbroken.

Geconcludeerd werd, dat de Watt Mountain Formatie diachroon tegen de Peace River Arch en de West Alberta Ridge moet zijn afgezet.

In de ondiepe baaien en lagunen, die zich op de verlaten deltagebieden vormden, werden de evaporieten en carbonaten van de Ft. Vermilion Formatie afgezet.

CURRICULUM VITAE

Peter Willem Smit werd op 21 october 1936 te Alblasserdam geboren. Hij heeft het eindexamen H.B.S.-B. in 1957 afgelegd aan het Gemeentelijk Lyceum te Dordrecht. Na het volbrengen van de dienstplicht, begon hij met de studie geologie aan de Rijksuniversiteit te Leiden. In mei 1963 werd het kandidaatsexamen behaald. Voor het doctoraalexamen studeerde hij sedimentologie met als bijvak ertsgeologie onder leiding van, onder anderen, Dr, A. J. Pannekoek en Dr. J. D. de Jong. Het doctoraalexamen werd afgelegd in maart 1966. Sinds April 1966 is hij werkzaam in de petroleum industrie in Canada. Van 1967 tot 1976 en sinds 1979 is hij werkzaam in de frontgebieden van de olie exploratie, zowel in Noord Amerika als daar buiten. In de tussenliggende jaren werkte hij in de provincies Alberta en British Columbia. Het werk aan deze dissertatie werd begonnen in 1969, en werd vooral in de avonduren verricht.

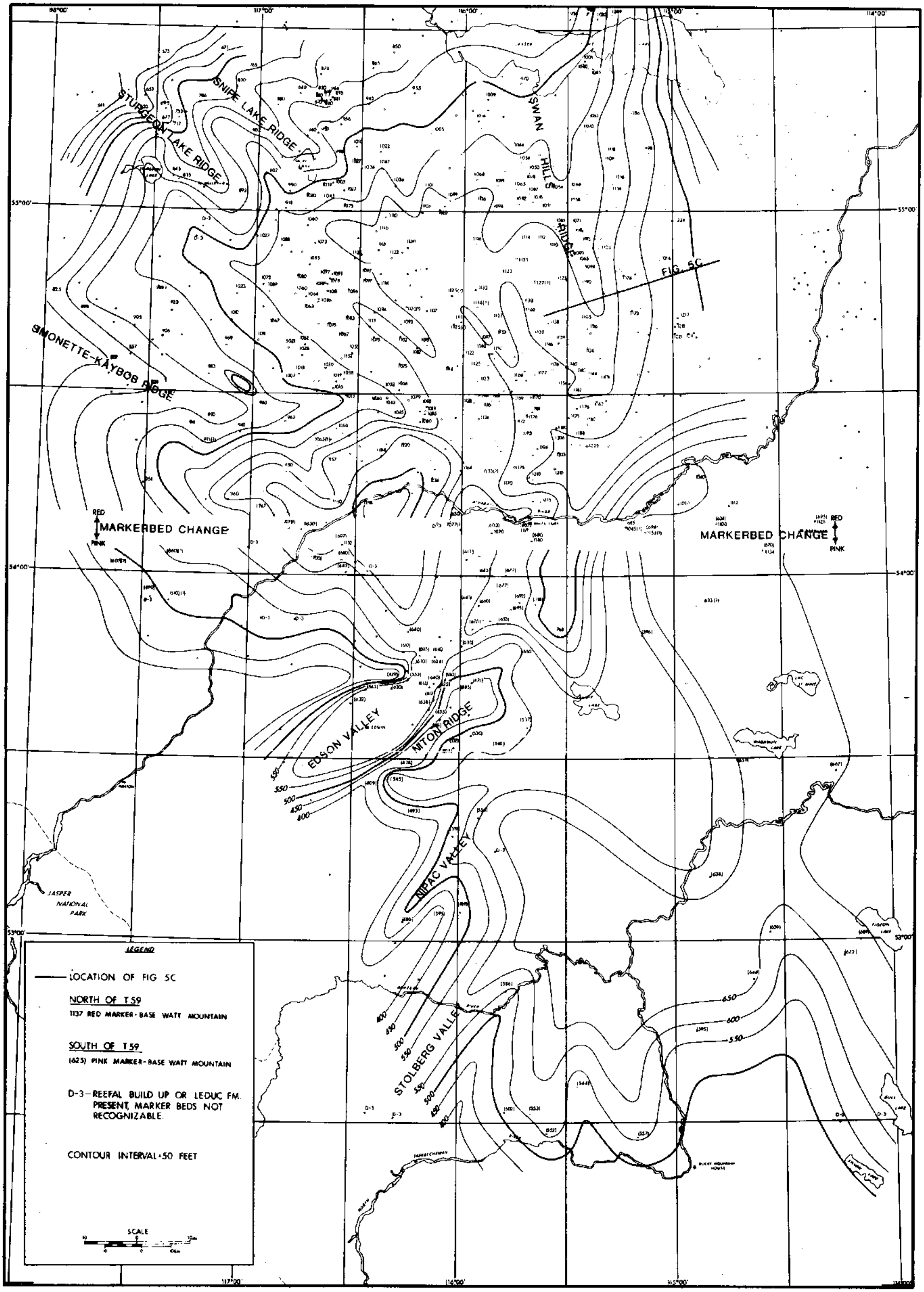


ATHABASCA RIVER AREA

FENCE DIAGRAM SHOWING THE

PRE-WATT MOUNTAIN SUBCROP

MAP 1

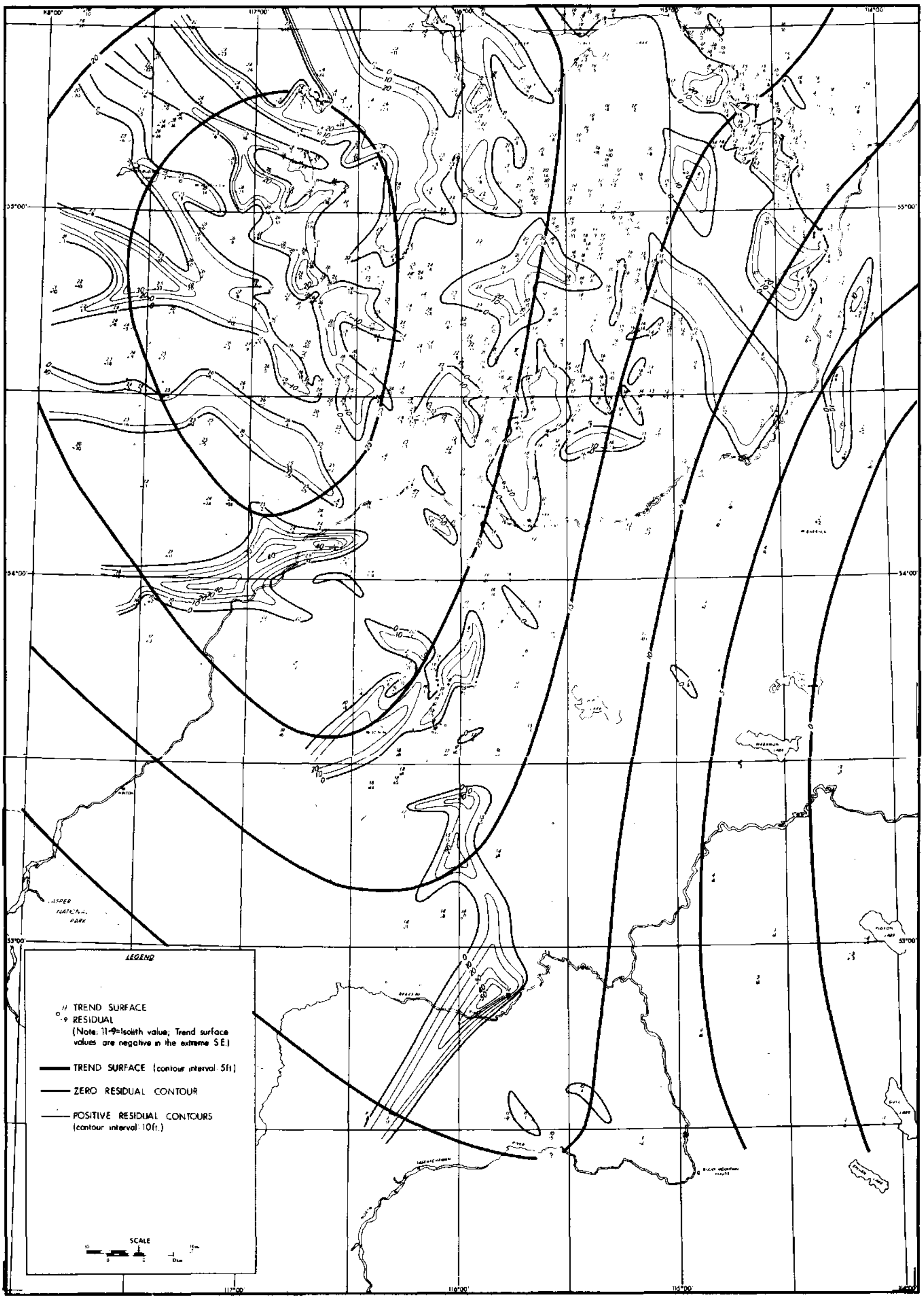


ATHABASCA RIVER AREA

PRE-GILWOOD

PALEOTOPOGRAPHY MAP

MAP 2



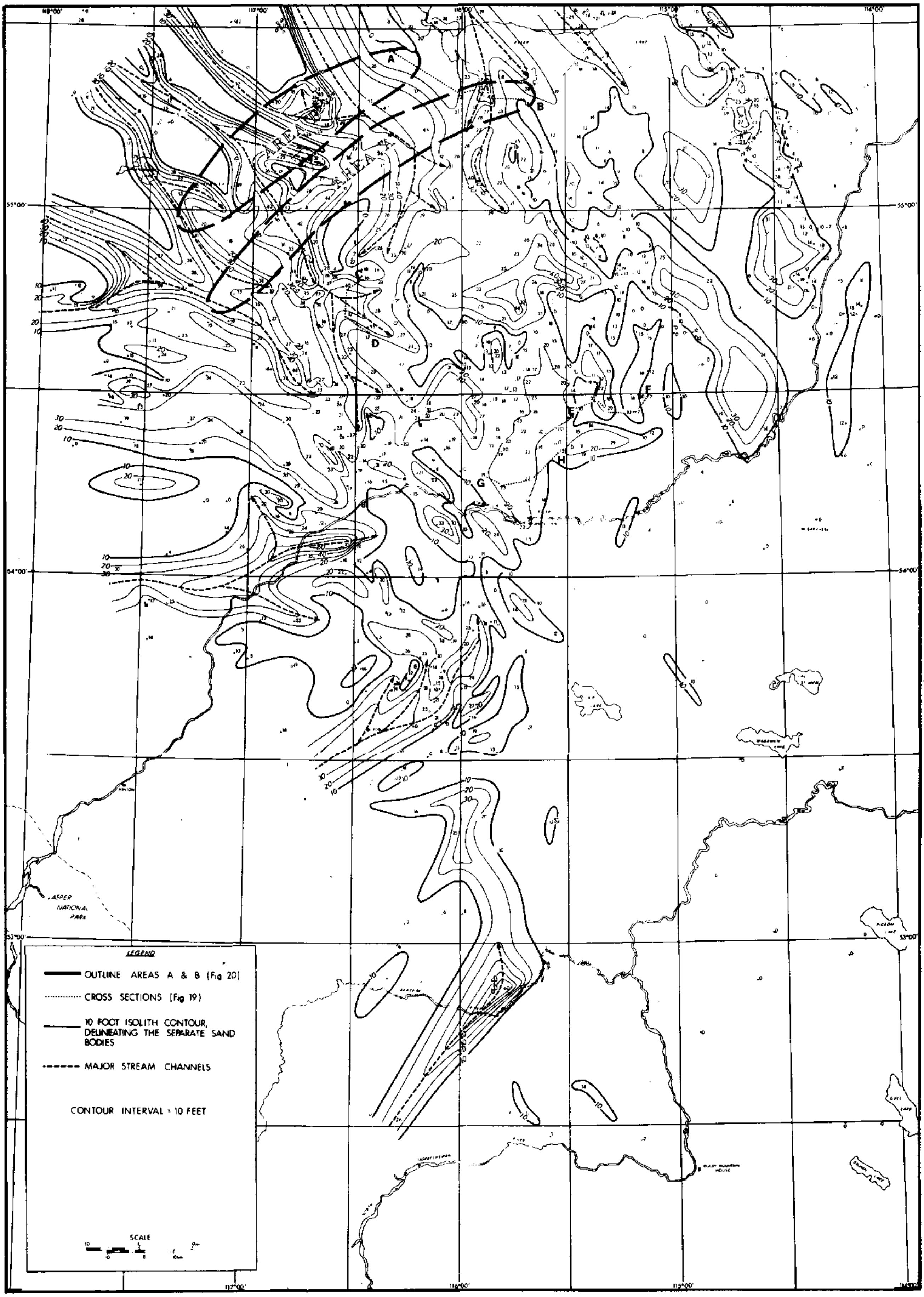
ATHABASCA RIVER AREA

TREND SURFACE ANALYSIS OF SAND ISOLITH

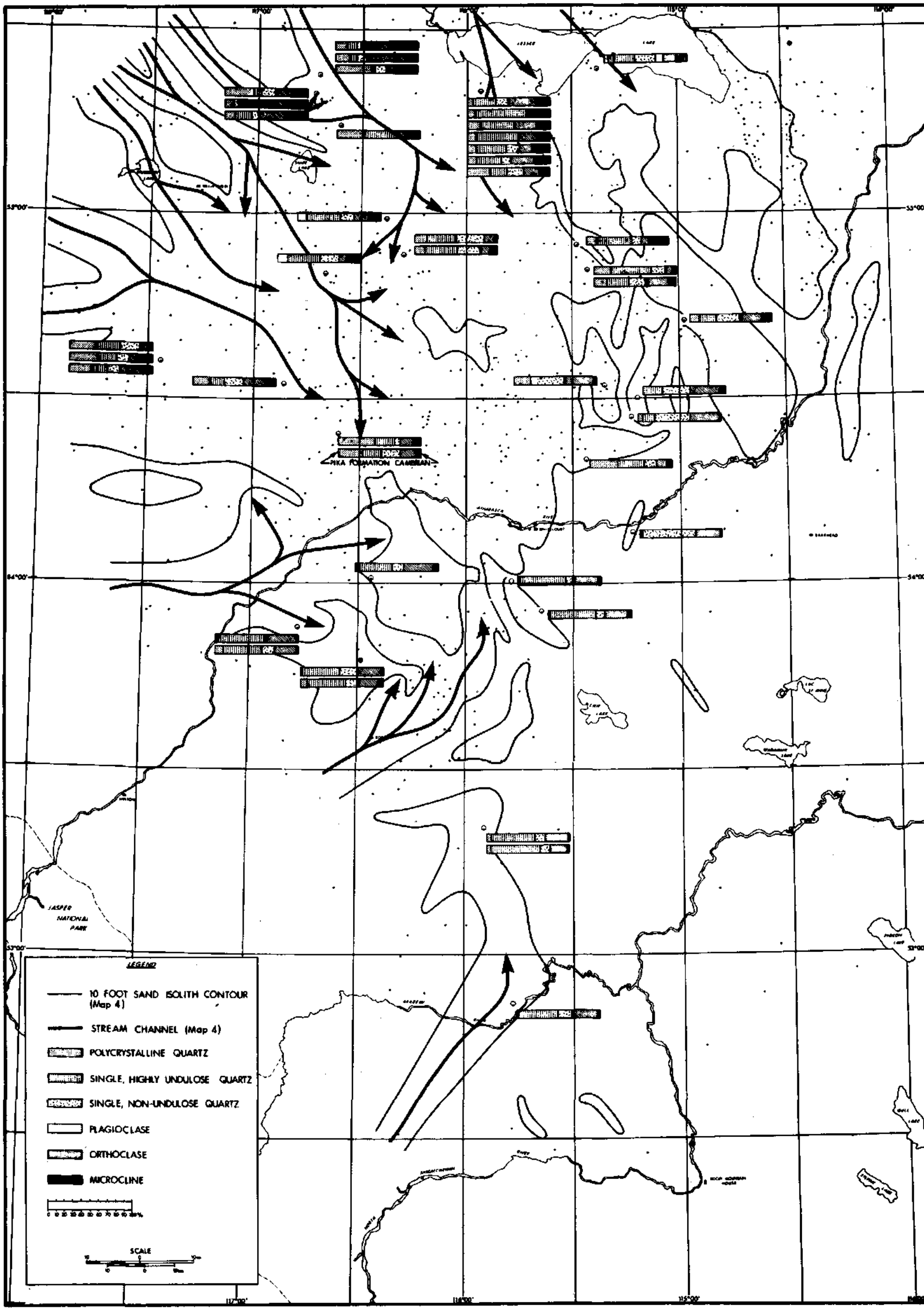
THIRD ORDER TREND SURFACE WITH

SUPERIMPOSED & POSITIVE RESIDUALS

MAP 3



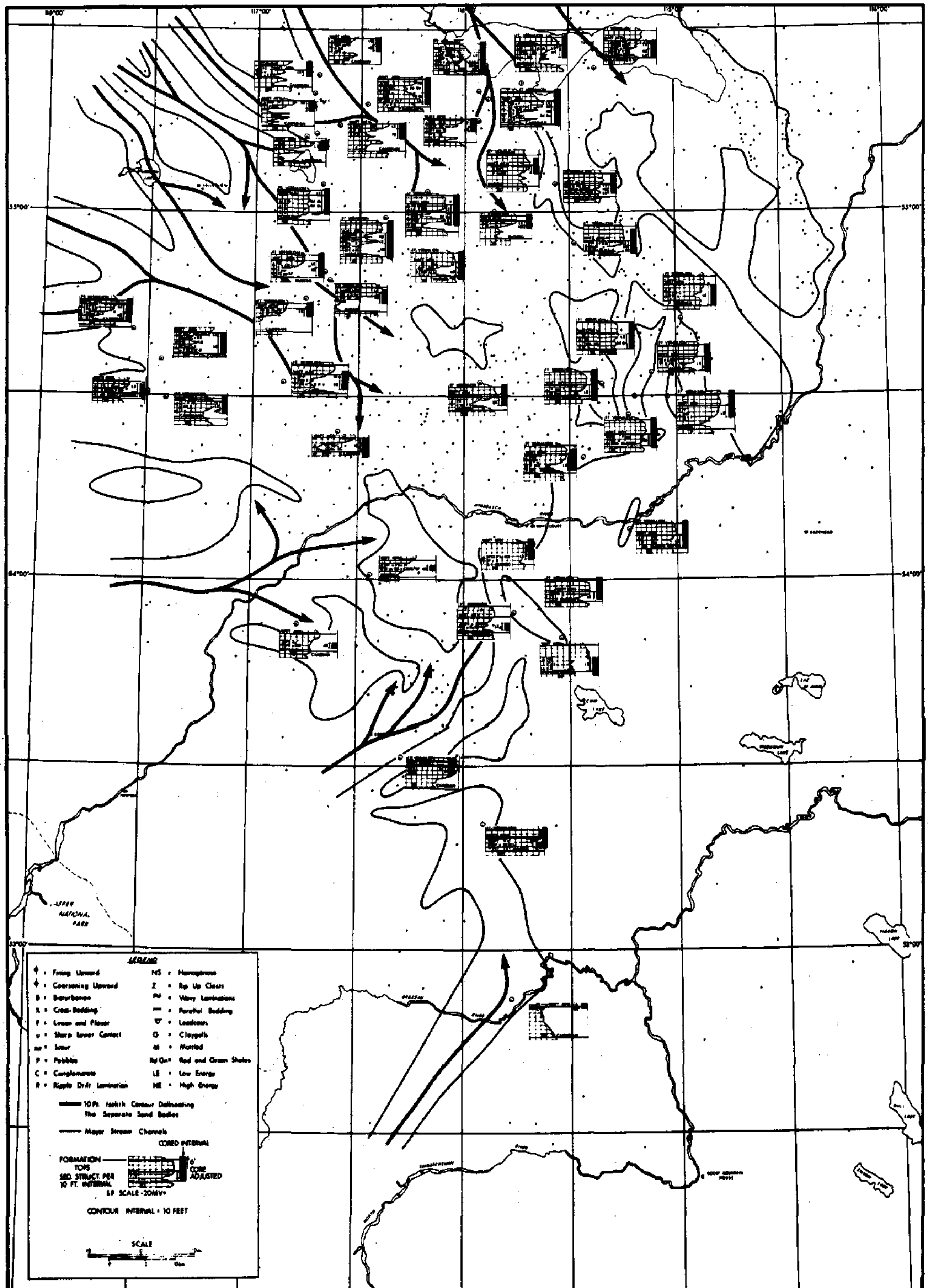
ATHABASCA RIVER AREA
GILWOOD ISOLITH
MAP 4



ATHABASCA RIVER AREA

QUARTZ AND FELDSPAR DISTRIBUTION

MAP 5



ATHABASCA RIVER AREA

GILWOOD ISOLITH WITH S.P. LOG CURVES & SEDIMENTARY STRUCTURES

MAP 6

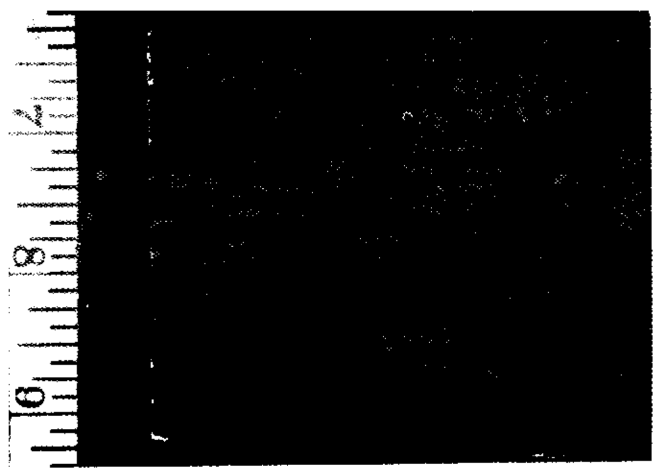
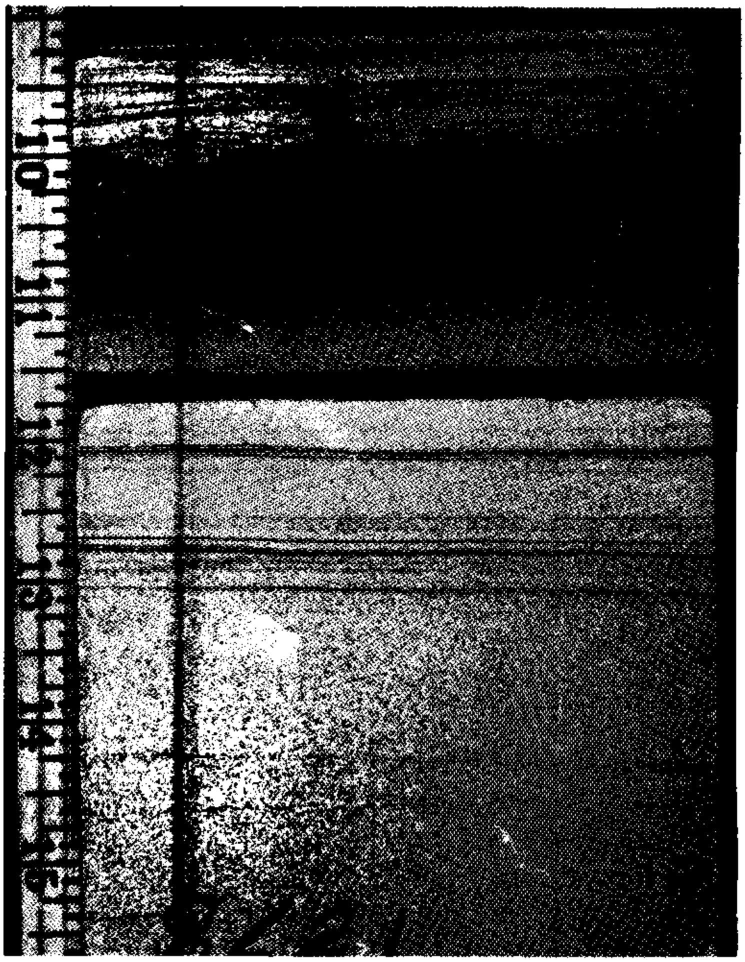


PLATE 1

SHALLOW MARINE AND LAGOONAL DEPOSITS

1 INCH



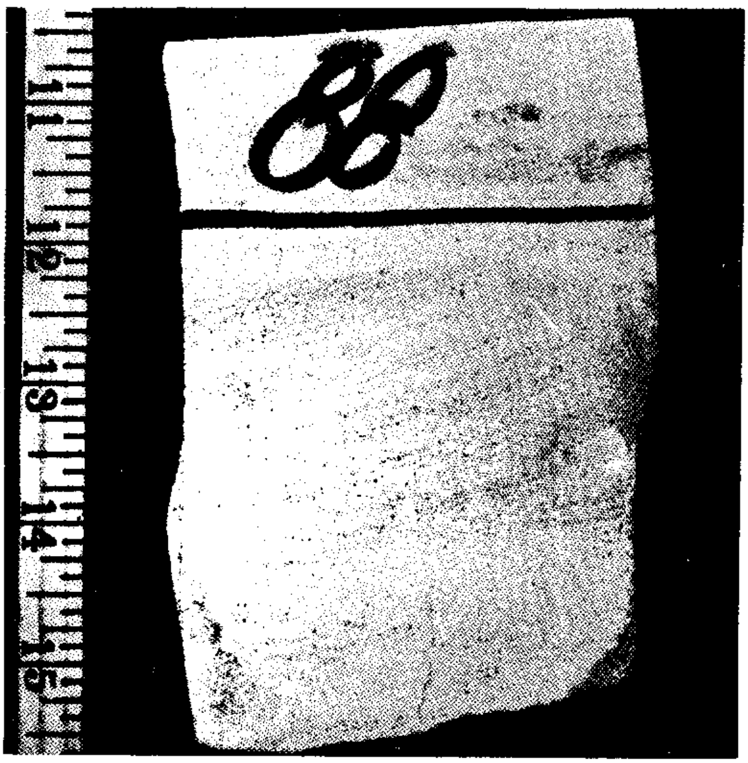


PLATE 2

BEACH BAR DEPOSITS

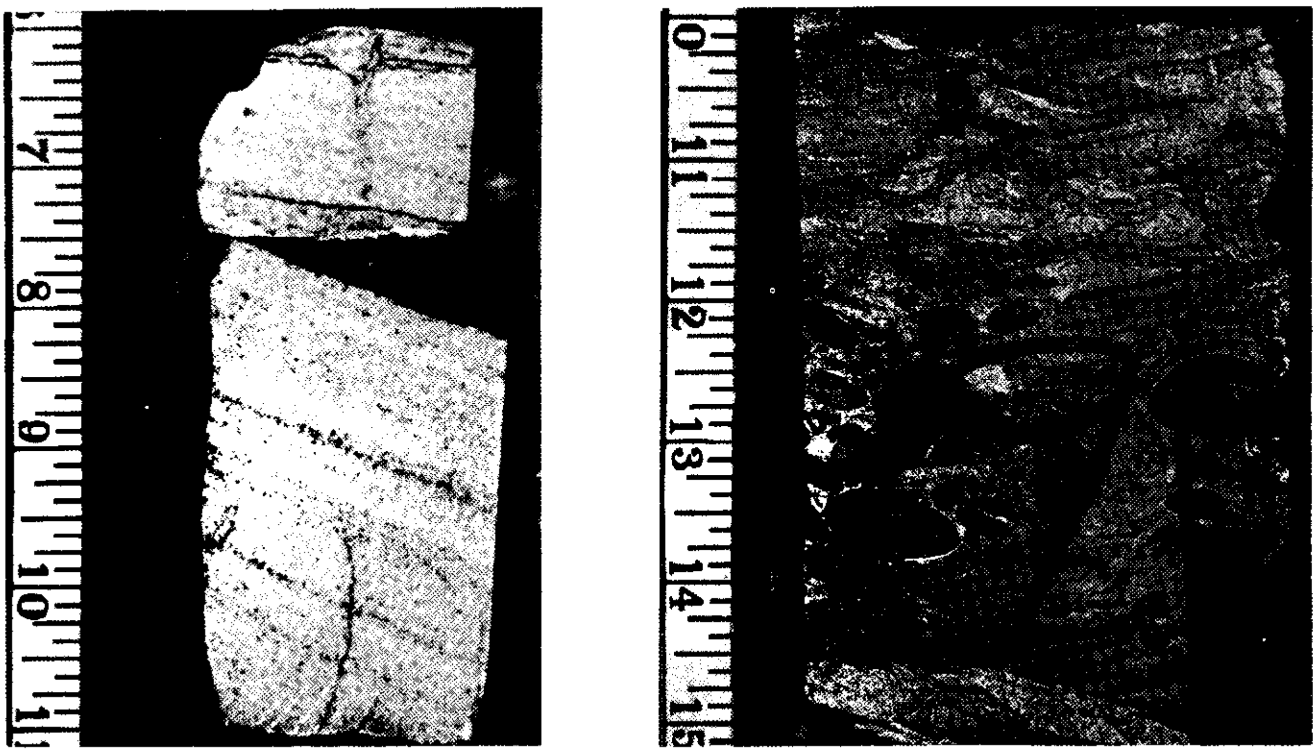


PLATE 3

CHANNEL DEPOSITS

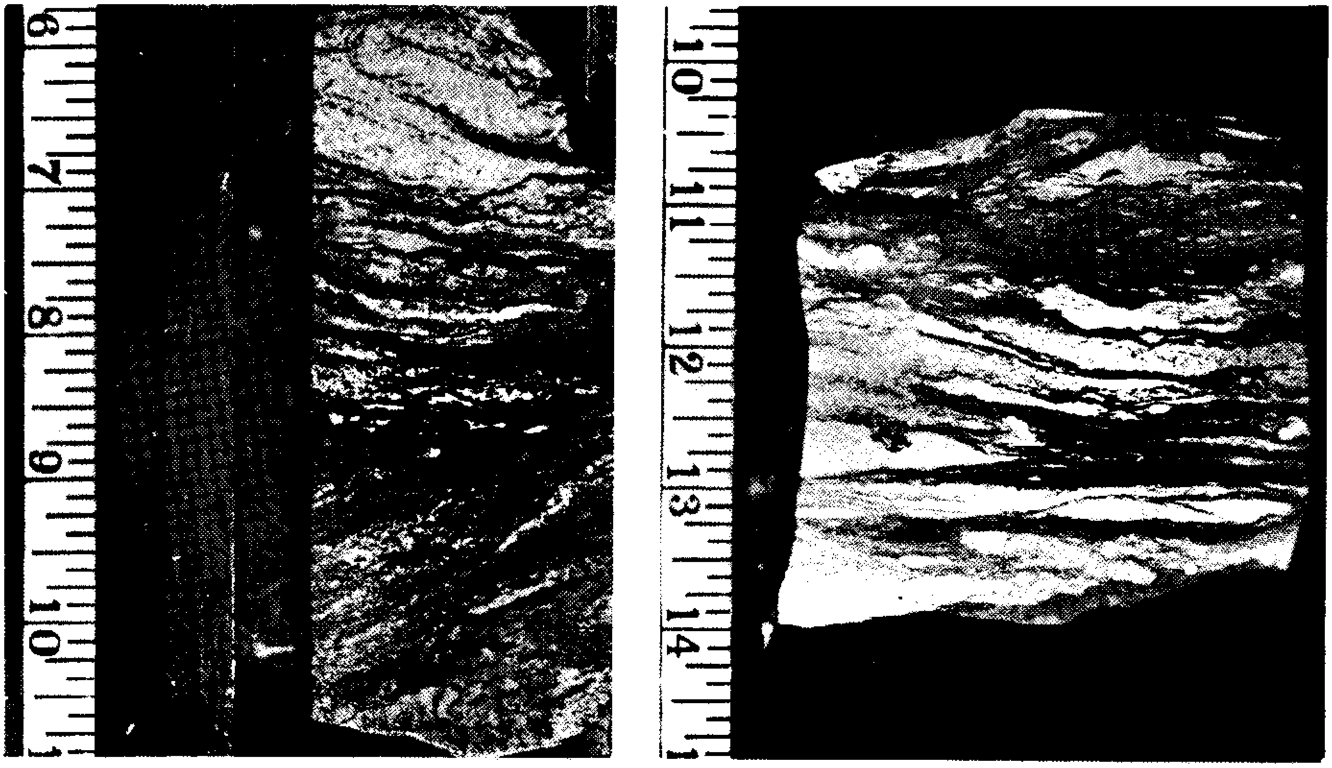


PLATE 4

TIDAL FLAT DEPOSITS

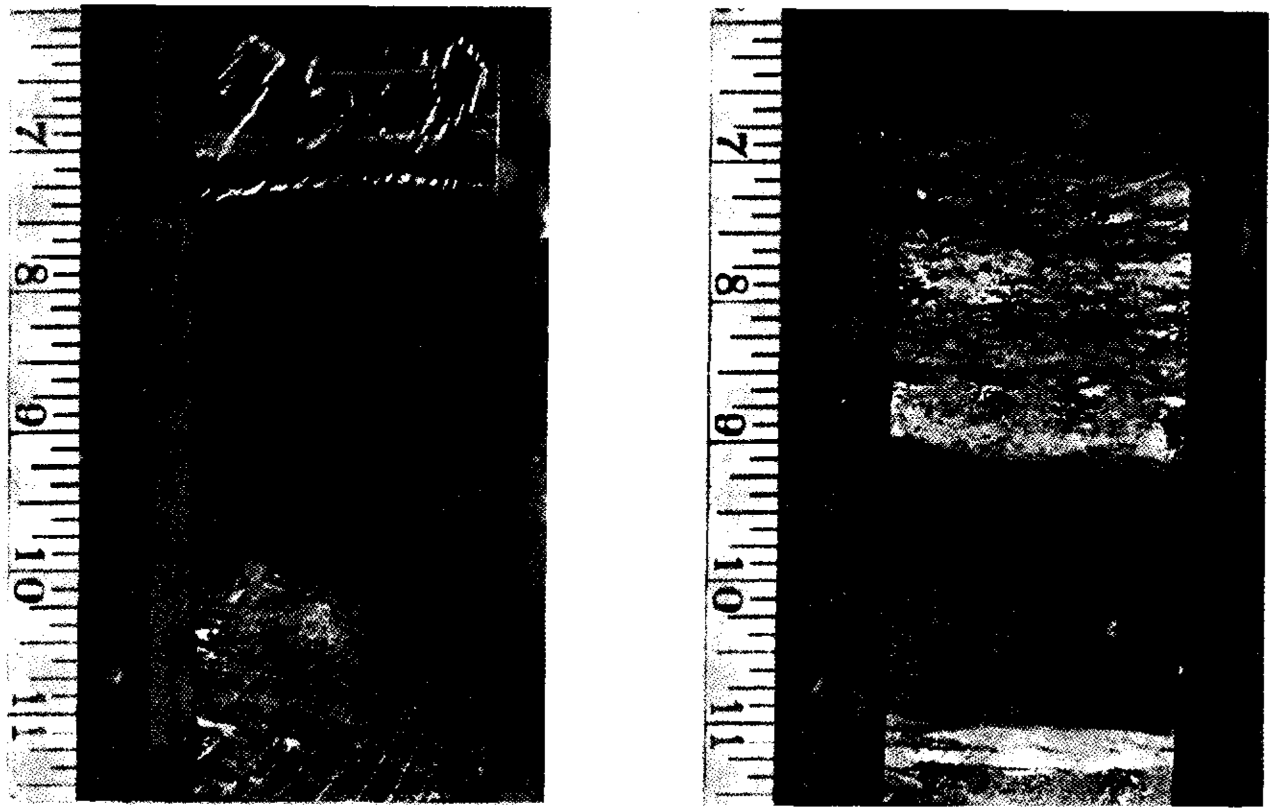


PLATE 5

MARSH DEPOSITS

PLATE 6

BROKEN QUARTZ GRAIN

9-17-73-18w5
@ 8092 (APPROX.)
CROSSED NICHOLS
45 X (APPROX.)