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THE UNIVERSITY OF ALBERTA

A Geotechnical Investigation of the Devonian Waterways Formation at the SANDALTA Lease

by

Brian Darrel Heald

A Thesis

Submitted to the Faculty of Graduate Studies and Research in Partial Fulfilment of the Requirements for the Degree of Master of Science in Civil Engineering

Department of Civil Engineering

Edmonton, Alberta
Fall 1983

THE UNIVERSITY OF ALBERTA

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Dr. D. M. Cruden ______________ Supervisor

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Dr. B. Stimpson ______________

Date: May 20, 1983

ABSTRACT

This thesis documents the geological and geotechnical features of the Upper Devonian Waterways Formation with respect to future mining ventures in the Athabasca oilsands.

Detailed descriptions of limestone core retrieved from the SANDALTA lease were employed in assessing the extent of solution, erosion and weathering upon the upper stratigraphic members. Structural interpretations and facies analyses were also completed.

Geotechnical investiga · ns included a summary of the overall rock mass quality and establishment of an empirical rock mass failure envelope. The impact of the observed geological features upon open pit and mine assisted in-situ projects is assessed and preliminary design guidelines are provided. The influence of paleotopography, hydrogeology and solution structures are emphasized.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1 General

Commercial production of synthetic crude oil from the Athabasca oilsands commenced in 1967 and has since accounted for less than 5% of the estimated total reserves of 114 billion m^3 of in-place bitumen (AOSTRA, 1980). Greater than 95% of the reserves are buried at depth and cannot be economically recovered by present surface mining techniques. Alternative in-situ and mine-assisted recovery methods have been proposed and are currently being evaluated by laboratory and pilot project studies.

Throughout the Athabasca region, approximately 70% of the oil bearing McMurray Formation is underlain by the Devonian Waterways Formation. Both in-situ and surface mining ventures interact with the Waterways and thus require a complete understanding of its geotechnical character and behaviour.

This study emerged from a recent proposal by the SANDALTA consortium to develop an open pit mine on the east bank of the Athabasca River (Figure 1.1). Reconnaissance drilling at this location generated increased concern about the geological features and engineering complexities of the Waterways Formation. This concern prompted a detailed

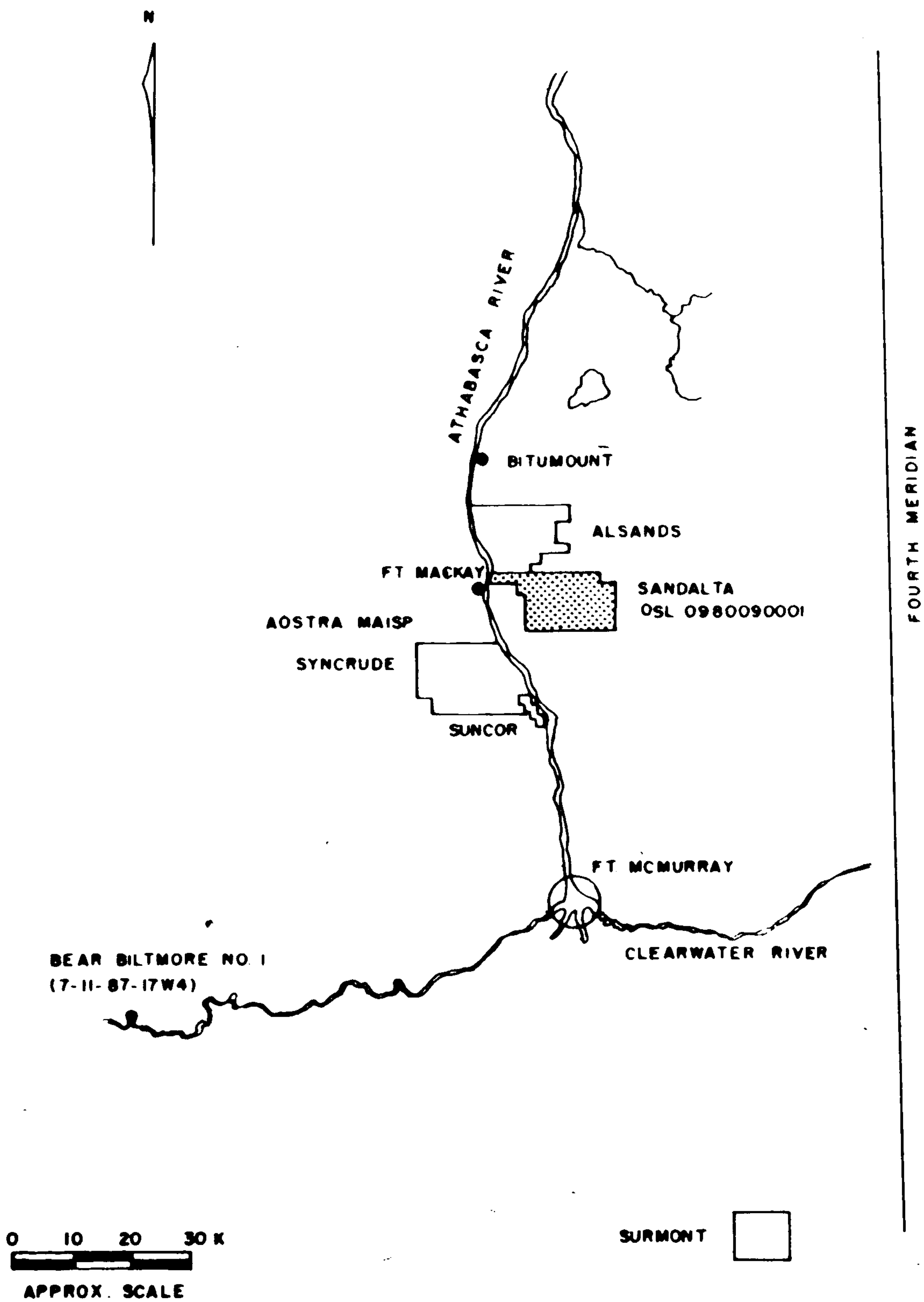


FIGURE 1.1: SITE LOCATION MAP - OSL 0980090001

in-house study whereupon the author was retained by Gulf Canada Resources Inc. (GCRI) in June, 1981. A preliminary report summarizing laboratory investigations was completed in December, 1981 and formed the basis for more recent research conducted independently at the University of Alberta.

1.2 Course of Study

The data base for this study consisted of approximately 2300 metres of 6 cm diameter core retrieved from 123 coreholes located throughout the SANDALTA lease (Figure 1.2). Approximately 18 metres of core was recovered from each borehole by diamond bit rotary coring techniques. All core was frozen on-site, then transported th GCRI's Calgary facilities where it was split in half, photographed and logged by staff geologists. Geophysical logs were completed in each borehole immediately following coring. All core was stored in an uncontrolled climate warehouse until review by the author, four to sixteen months later. At the time of review, all core displayed a high degree of subhorizontal fracturing. This phenomenon was particularly pronounced in the fissile calcareous shales and was thought to be due to a combination of dessication, handling and possibly core disking.

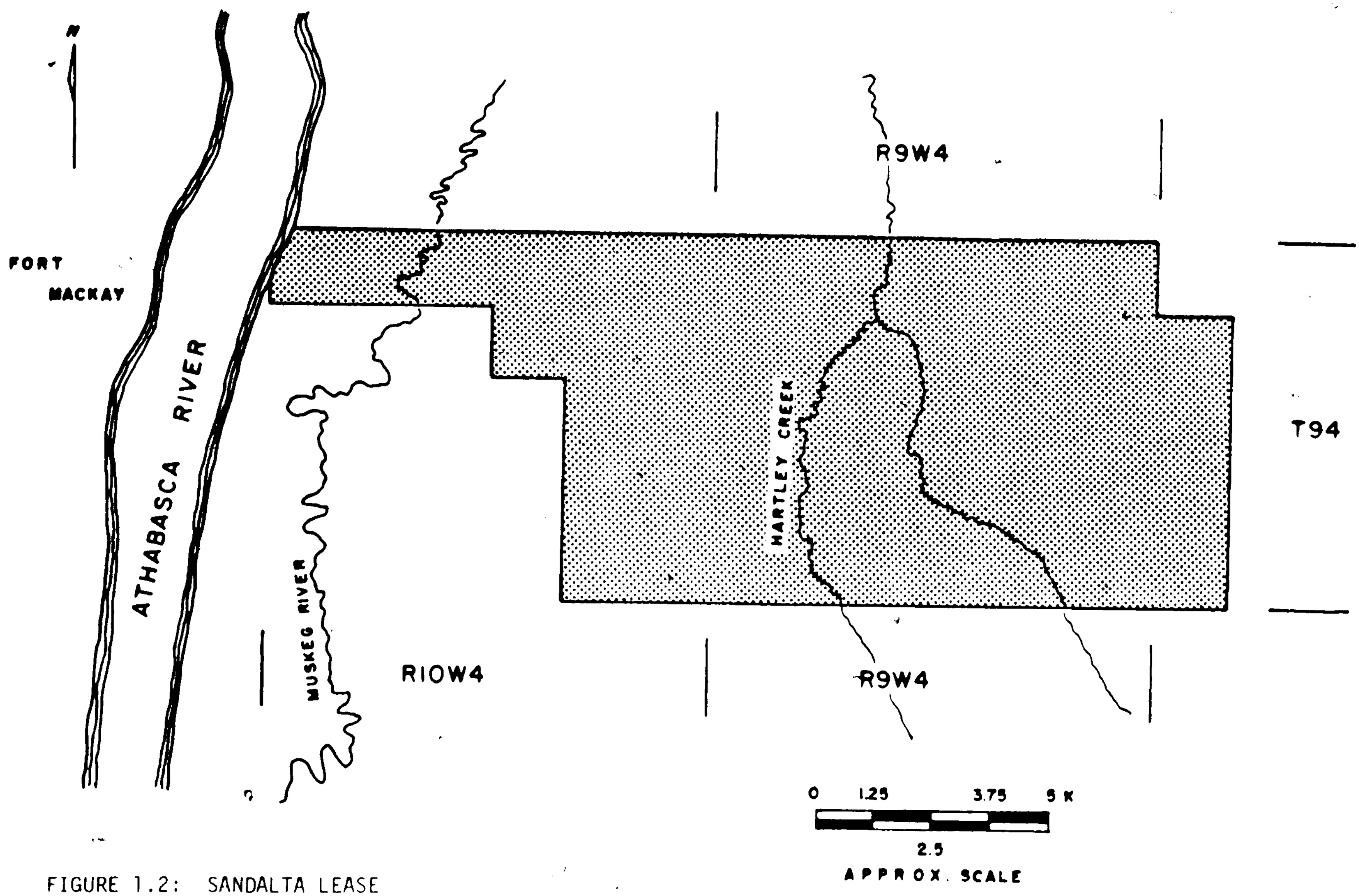


FIGURE 1.2: SANDALTA LEASE

Mean core recovery exceeded 95%, thereby facilitating rapid correlation with geophysical logs. Although drilling records did not report rapid ground losses, missing core sections may represent eroded soft materials or subsurface voids.

Following completion of the descriptive logging, carbonate facies models and geophysical cross plots were employed in distinguishing the various core lithologies. Vertical cross-sections were created to establish stratigraphic correlations and facies boundaries. Subsequent studies emphasized erosional, weathering and solution features and the geotechnical impact of these features upon expected recovery projects.

1.3 Aim and Scope of the Study

This thesis reviews current knowledge of the Waterways Formation and discusses Upper Devonian structural features underlying the SANDALTA lease. The study also assesses the effect of geological features upon open pit and mine-assisted recovery projects. Generalized recommendations for mine development are included.

Some of the questions to be addressed include the following:

1. What are the characteristics of solution features

on the Devonian surface and at depth?

2. What are the features of deep-seated collapse structures and are they potentially unstable?
3. Is solution presently occurring and if so, where, and how aggressively?
4. What other structural features characterize the Waterways and what effect will they have upon mine development?
5. What are the characteristics of early Cretaceous erosional channels and their infillings?
6. How well developed and widespread are weathering features such as paleosols?
7. Is the rock mass generally suitable for tunnel and shaft construction?
8. What are the hydrogeologic properties of the rock mass?
9. What is the in-situ state of stress?
10. How will the rock mass respond to changes in the stress field due to mine development and thermal stimulation?
11. Is deep-seated highwall stability a concern?
12. Are mine floor collapse structures unstable?

It is emphasized that the study does not provide detailed paleontologic or biostratigraphical analyses. Moveover, the findings are subject to inherent limitations including the following:

1. The observed core represents two of the six Waterways members. The remaining four members and Middle and Lower Devonian units remain unexamined. Regional structural conclusions are necessarily based upon inference from shallow core.
2. Structural observations such as fracture type and density are inherently biased as they were derived exclusively from vertical core.
3. Regional corehole data with which to compare detailed site findings was not readily available.
4. Stratigraphic control was difficult to establish due to high vertical and lateral variability in lithology.
5. Core and outcrop findings could not be confirmed in underground excavations.
6. The present level of geotechnical data is insufficient for design purposes.

Despite these limitations, it is hoped the findings of this study will prove useful for future Waterways investigations. Many areas of geotechnical interest remain unexplored.

2. CURRENT KNOWLEDGE OF THE WATERWAYS FORMATION

2.1 Lithology and Stratigraphy

2.1.1 General

Many authors have documented the lithology and regional stratigraphy of the Waterways Formation. In particular, studies by McDonald (1947), Belyea (1952), Crickmay (1957), Carrigy (1959), Norris (1963, 1973) and Norris and Uyeno (1981) are the most descriptive.

Richardson (1851) first reported limestones in outcrop along the Clearwater and Athabasca Rivers, but it was Warren (1933) who applied the Waterways name to the rock mass overlying the Middle Devonian Evaporite Formation. McDonald (1947) later described the upper Devonian lithologies, however Crickmay (1957) originally subdivided the formation into five members based upon the 214 metre type section at the Bear Biltmore well (7-11-87-17W4) located 80 kilometres west-southwest of Ft. McMurray (Figure 1.1). The five members were the Mildred, Moberly, Christina, Calumet and Firebag members in descending order (Figure 2.1). Fong (1959, 1960) later defined the Swan Hills Member, a reefal carbonate named after its type location.

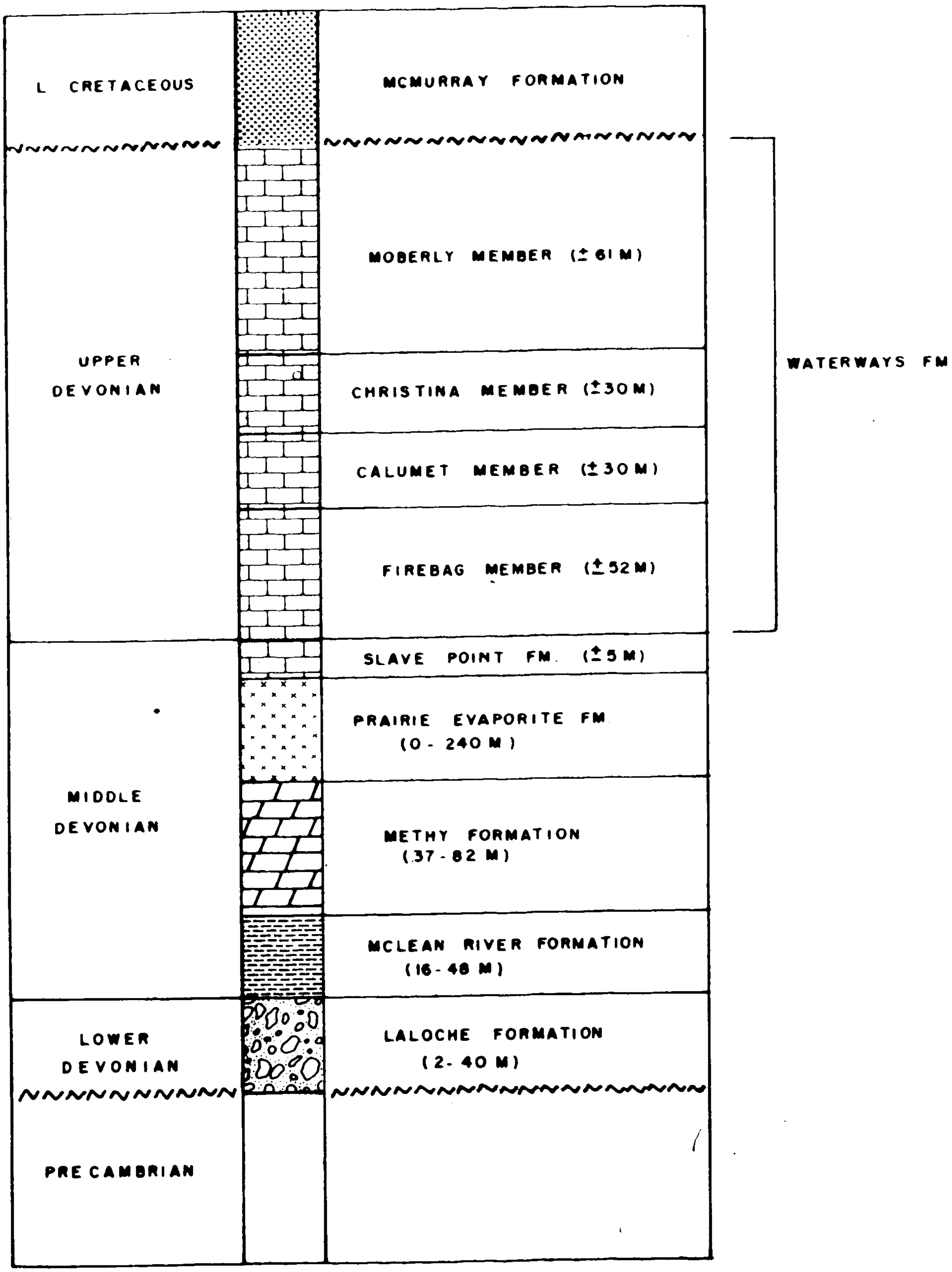


FIGURE 2.1: LOCAL STRATIGRAPHIC COLUMN

In the Bear Biltmore type section, the Waterways lies between the Middle Devonian (Givetian) Slave Point Formation and the Upper Devonian (Middle Frasnian) Cooking Lake Formation. It is thus early Frasnian in age. Both upper and lower contacts are conformable.

In the Ft. McMurray area, the Waterways is unconformably overlain by the Lower Cretaceous McMurray Formation. The Upper Devonian Cooking Lake, Ireton and Grosmont Formations were removed prior to Lower Cretaceous deposition. The Devonian-Cretaceous unconformity represents combined Carboniferous, Permian, Triassic and Jurassic time, a total of approximately 250-300 million years.

At the SANDALTA lease, the Waterways comprises a southwesterly dipping regional monocline with a dip of less than 10°. Total documented thickness ranges from 214 to 274 metres (Norris, 1963, 1973) in a wedge-shaped unit which thickens toward the southwest (Figure 2.2). Deposition occurred within the Western Canadian sedimentary basin during Upper Devonian (Frasnian) time.

Warren (1951) discussed the transgression and regression of the Middle Devonian Boreal Sea. It was considered to have been a shallow epeiric sea extending from the present Arctic to the southern United States and from the Selkirk Mountains to the Canadian Shield in Manitoba. Withdrawal of this sea resulted in evaporite formation which was in turn followed by transgression of a more widespread,

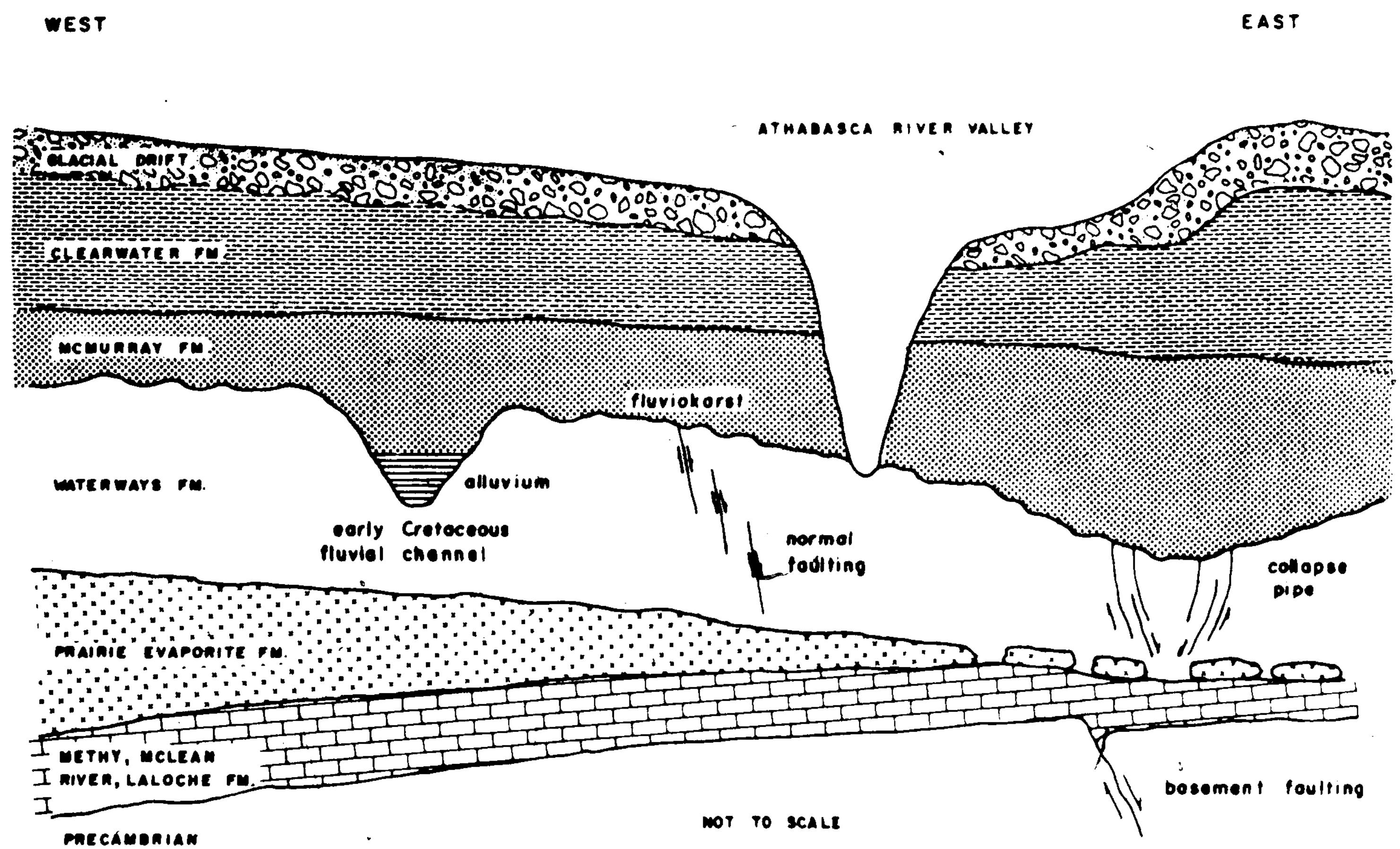


FIGURE 2.2: IDEALIZED REGIONAL CROSS SECTION

Upper Devonian epeiric sea. This sea was characterized by three primary cycles of transgression and regression. The first transgression is considered to have deposited the argillaceous carbonates of the Waterways Formation. Thus the bottom of the Waterways defines the commencement of Upper Devonian deposition. The Middle Devonian Slave Point Formation is also recognized as a transgressive unit. Their mutual contact is believed to be conformable (Norris 1973).

Underlying the Slave Point Formation are the Middle Devonian Prairie Evaporite Formation (0-240 m), Methy Formation (37-82 m) and McLean River Formation (16-48 m) (Figure 2.1). Immediately underlying these units is the Lower Devonian LaLoche Formation (2-40 m) which unconformably overlies the Precambrian basement in the study locale.

Overlying the Waterways is the unconformable Lower Cretaceous McMurray Formation. As mentioned, the Upper Devonian Cooking Lake, Ireton and Grosmont Formations were removed prior to Lower Cretaceous deposition. These units are present to the southwest in Crickmay's (1957) type section. They were found to be conformable with the Waterways at that location. The Upper Devonian erosional surface dips gently to the southwest and exposes progressively younger units westward.

Belyea (1952) correlated the Waterways of the Athabasca region with the Beaverhill Lake Formation of

Central Alberta. In addition, Belyea and McLaren (1957) described an approximate Waterways equivalent to the northwest, the lower half of the Hay River Formation. Bassett (1952) described Waterways fauna and correlated the formation with stratigraphic equivalents throughout the central United States.

2.1.2 Precambrian

Carrigy (1959), Ells (1932) and Sproule (1951), each described local "bosses" of Precambrian quartzite in Township 94, Range 10, immediately west of the SANDALTA lease. These metasediments are thought to represent the Churchill Province of the Canadian Shield. They are Archean in age and reportedly intruded by granites and granitic gneisses which were in turn crosscut by pegmatitic and aplitic veins and diabase dykes (Carrigy, 1959).

2.1.3 Lower Devonian

The LaLoche Formation was named by Norris (1963) to represent the early Devonian granite washes, arkosic sandstones and claystones that nonconformably overlie the Precambrian basement. The type section occurs along the Clearwater River southeast of Ft. McMurray. Norris (1973) indicated that these units often appear only in Precambrian depressions and that considerable thinning occurs over Precambrian highs.

At the type section, the LaLoche Formation is less than 2 m thick, however it thickens towards the north to 40 metres (Norris 1973). The upper contact is conformable with the Middle Devonian McLean River Formation and thus it is considered to be Early Devonian. Outcrop lithology consists predominantly of light brown, fine to medium grained, thinly bedded, feldspathic sandstones. Iron oxide staining suggests intermittent subaerial exposure. Secondary lithologies include sandy dolomites, mudstones, shales and minor beds of anhydrite and gypsum (Norris, 1973). Basal deposits consist of weathered igneous and metasedimentary rocks or "granite wash".

2.1.4 Middle Devonian

The early Middle Devonian McLean River Formation was also named by Norris (1963) to represent the sandy dolomites, shales and siltstones that immediately overlie the Lower Devonian LaLoche Formation. Again, the type section is on the Clearwater River, southeast of Ft. McMurray. Both upper and lower contacts are conformable and well defined. The upper contact is distinguished by a gross lithologic change from fine grained clastics to the marine carbonates of the Methy Formation.

The thickness of the McLean River at the type section is 18.6 metres. Its maximum thickness to the north is 344 metres (Norris, 1973). Outcrop lithologies consist of light grey, fine grained, medium to thick bedded sandy dolomites with interbedded olive, calcareous sandy shales and mudstones. Occasional dolomitic siltstones, sandy shales, mudstones and interbedded anhydrite and gypsum have been observed west of the type section (Norris, 1973). On the basis of fossil content and stratigraphic position, the McLean River Formation is early Middle Devonian (Eifelian) in age.

The Middle Devonian Methy Formation was first referenced by Nauss (1950), however it was Greiner (1956) who defined the type section at location 9-36-88-8W4. Subsequent work by Carrigy (1959) and Norris (1963) provided more lithologic detail. The Methy Formation conformably separates the overlying Prairie Evaporite Formation from the McLean River dolomites and shales.

Greiner (1956) defined three lithologic subdivisions. First, a relatively thin bedded, grey, basal silty dolomite and evaporite unit with thin interbeds of anhydrite and shale. Total thickness varies from 1-11 metres. The second unit consists of brown to grey, poorly to well bedded dolomite, often flow layered and brecciated. Reefal and interreefal beds are also common. Thickness varies from 40-61 metres. The third, upper unit consists of well bedded dolomites and evaporites which are often argillaceous. Thin beds of anhydrite are characteristic. Thickness varies from 1-17 metres.

Based on stratigraphic equivalence and paleontologic content, the Methy Formation is considered to be late Eifelian to late Givetian in age (Norris, 1973). Total thickness varies from 37 to 82 metres.

Conformably overlying the Methy are the anhydrite beds of the Prairie Evaporite Formation. The Prairie Evaporite was named by Baillie (1953), and although the formation does not outcrop along the Athabasca or Clearwater Rivers, it is present west of the Athabasca. In the Bear Biltmore No. 1 well, Carrigy (1959) subdivided the formation into two units. The lower unit consists of grey halite with brownish grey anhydrite beds throughout. Its thickness in the type section is 212.5 metres. Finely interbedded siltstones are also common. The upper unit consist of silty shales, dolomitic shales and mottled silty anhydrite with some dolomite and limestone. Its thickness in the type section is 25 metres. Total formation thickness varies from zero at SANDALTA (GCRI, 1981) to 237.5 m in the Bear Biltmore No. 1 well. The age of the Prairie Evaporite is based on stratigraphic position and is late Middle Devonian (Givetian) (Norris, 1973).

Disconformably overlying the Prairie Evaporite is a thin series of carbonate rocks, named the Slave Point

Formation by Cameron (1918). Eastward near the Alberta-Saskatchewan border, the Slave Point overlaps both the erosional and depositional edge of the Prairie Evaporite and thus rests directly on the Methy Formation. The upper contact is defined by a change in both fauna and lithology and is paraconformable with the Waterways Firebag Member.

The Slave Point Formation does not outcrop in the study area, however borehole lithologies include argillaceous limestones, siltstones and dolomitic limestones. The carbonates are often brecciated and there is a lack of macrofossils. Thickness ranges from 1.7 metres in the Bear Biltmore No. 1 well to approximately 5 metres in the SANDALTA locale (Norris, 1973). The Slave Point thickens considerably to the west and northwest. The age of the Slave Point Formation is late Middle Devonian (Norris 1973).

2.1.5 Upper Devonian

Several authors have compiled lithologic descriptions of the various Waterways Members. Although Warren (1933) first named the formation, Crickmay (1957) defined the five members currently recognized. The Upper Devonian Grosmont, Ireton and Cooking Lake Formations were removed during the net erosional period separating Upper Devonian and Lower Cretaceous time. This hiatus represents

250-300 million years.

The basal Firebag Member consists of olive calcareous shale with thin, interbedded argillaceous limestones and non-calcareous shales. A fragmental limestone is common at the base (Norris, 1973) and may be accompanied by halite. Thickness in the type section is 52 metres, however this increases northeasterly to approximately 59 metres at SANDALTA (GCRI, 1981). A subtle northwesterly dip of less than 5° is evident throughout the study region.

Norris (1963) reported that the Firebag contained very few species of brachiopods, however Crickmay (1966) recognized two distinct fossil zones which have been used to correlate the Firebag with similar members throughout western Canada and the northwestern United States.

The Calumet Member conformably overlies the Firebag Member and consists of grey to buff, clastic and microcrystalline argillaceous limestones with interbedded, olive calcareous shales and minor non-calcareous shale. Norris (1963) described four lithologies in detail from outcrop located along the Clearwater River.

Immediately south of Ft. McMurray, at Township 83, the Calumet limestone has less than 10% argillaceous content at the top and becomes increasingly argillaceous toward the bottom where the clay content may be 20% - 30% (GCRI, 1981). The Calumet also displays a much higher faunal content than either of the adjacent Firebag or Christina Members. It is characterized by a high bioclastic debris content and is commonly classified as a wackestone. The thickness of the Calumet is constant over a large area. It is 31 metres thick in the type section. Both upper and lower contacts are conformable and marked by distinct lithologic changes. Again, a northwesterly dip of less than 5° is observed.

The next member in ascending order is the Christina Member. The Christina consists primarily of olive grey calcareous shales which grade vertically into a thin grey argillaceous limestone. Norris (1973) also reported minor light brown aphanitic and fragmental limestones. At Township 83, Range 6, the Christina possesses two repeating limestone-shale cycles and a northwesterly regional dip of 1° (GCRI, 1981). Clay content may reach 15% and the calcareous shales are commonly 40% - 50% carbonate (GCRI, 1981). Fossils are not common in the Christina, however several bryozoan species may be observed (Norris, 1973). Submarine hardgrounds are a common occurrence. Thickness varies from 23 to 37 metres (Norris, 1973).

Conformably overlying the Christina is the thick Moberly Member. The Moberly comprises an alternating sequence of olive, finely interbedded to rubbly argillaceous limestones and calcareous shales with light brown, hard fragmental limestones. Argillaceous content increases toward the top of the member and in a northerly direction. Immediately south of Ft. McMurray, the basal 3-4 metres is a grey calcareous shale similar to those present in the Christina (GCRI, 1981). Light brown, micritic, nodular textures have also been observed at this location (Township 83, Range 6).

Norris (1973) noted that throughout the McMurray area, the Moberly Member subcrops on the Devonian-Cretaceocus unconformity. Total recorded thickness varies to 61 metres in the type section. Fossils are abundant and include brachiopods, crinoids, and stromatoporoids. Norris (1963) provided a complete list of species.

The uppermost member of the Waterways Formation is the Mildred Member. Although the Mildred does not outcrop in the immediate Ft. McMurray area, its lithology is known from regional boreholes. Olive-grey calcareous shales, argillaceous limestones and light brown clastic limestones are characteristic. Both upper and lower contacts are conformable. The Mildred is 43 metres thick in the type section, but has been completely eroded at SANDALTA.

Additional geologic information pertaining to all Waterways Members includes mineralogic, petrologic and structural features. In general, all Waterways carbonates are lime mud-supported with few grain-supported lithologies. The supporting carbonate mud or micrite is predominantly microcrystalline calcite with scattered rhombs of dolomite or ankerite. Small percentages of the clay minerals illite, kaolinite and chlorite have also been distinguished (GCRI, 1981). Moberly and Christina shales commonly contain 50% - 60% calcite as cement or matrix and may therefore be considered to be carbonate muds or micrites. They continue to be classified as shales due to their textural uniqueness. Bulk mineral analyses reveal the presence of minor ferroan dolomite and quartz. Minor siderite and halite have also been recorded (GCRI, 1981).

Both primary porosity and permeability in the Moberly and Christina are expected to be low. Secondary jointing, weathering and solution exercise the greatest influence upon both parameters. In-situ measurements have not been made.

McDonald (1947) discussed the high density of the Waterways and suggested there was no primary gypsum. All gypsum was proposed to be rehydrated anhydrite. McDonald (1947) further reported that epithermal calcite and marcasite veining was common. Marcasite was commonly found as a fossil replacement in veins in shales, as coatings on nodules and as disseminated grains. McDonald (1947) suggested that the iron sulphides were not detrital, but rather, secondary in origin. Calcite veining suggests a similar hydrothermal origin.

McDonald (1947) also attributed the high calcareous content of the "shales" to a more epicontinental depositional environment. Their characteristic olive color was not attributed to the presence of glauconite but rather to the presence of ferrous iron compounds. He suggested that the formation of carbonate nodules was contemporaneous with deposition and that the common mottled texture may be due to processes such as organic decay, bioturbation, calcite replacement and cyclic carbonate - micrite deposition. Belyea (1952) suggested that the finely interbedded character may be attributed to an unstable shelf environment where continual shallowing was dominant.

In summary, the Waterways members consist primarily of interbedded argillaceous limestones and calcareous shales. The suggested marine environment is a shallow, epicontinental slope or platform.

2.2 Structural Geology

Mesoscopic structural features such as laminations, banding, brecciation and bioturbation are described in detail in Sections 3.6.1 and 3.6.2. The larger regional features dominate the structural geology and are presently considered.

The Paleozoic section overlying the westerly sloping Precambrian basement forms a southwesterly dipping regional monocline that exhibits numerous local basins and faults. The monocline strikes north-northwest and thickens toward the west (Figure 2.2). Erosional hiatuses exist at both the upper and lower contacts.

Hume (1947) first reported Waterways flexures with amplitudes of 15-30 metres and wavelengths of several hundred metres to a kilometre. These basins were thought to be circular in plan and thus without a predominant strike direction. The absence of a regional fold trend suggests they were not formed by tectonic compression. Hume (1947) considered anhydrite-gypsum volume changes to be the most likely source of surface undulations. Further discussion by Allan (1947) indicated that there was insufficient gypsum to have caused widespread deformation. Other potential mechanisms include differential solution and subsidence or salt diapirism. Williams (1980) thought that a regional south-southwest fold trend could be distinguished. Carrigy (1959) attributed surface flexures to the solution process and further suggested that solution was structurally controlled by a northwest striking fault (Figure 2.3).

Several authors have suggested the presence of regional faulting. Sproule (1932) proposed a northwest striking fault along the Clearwater River with the downthrown side to the west. Kidd (1951) suggested this movement took place in Lower Cretaceous time, thus affecting both the Waterways and McMurray Formations. Stewart (1963) related the distribution of McMurray sands to structural features such as the Nisku-Grosmont topographic high, Elk

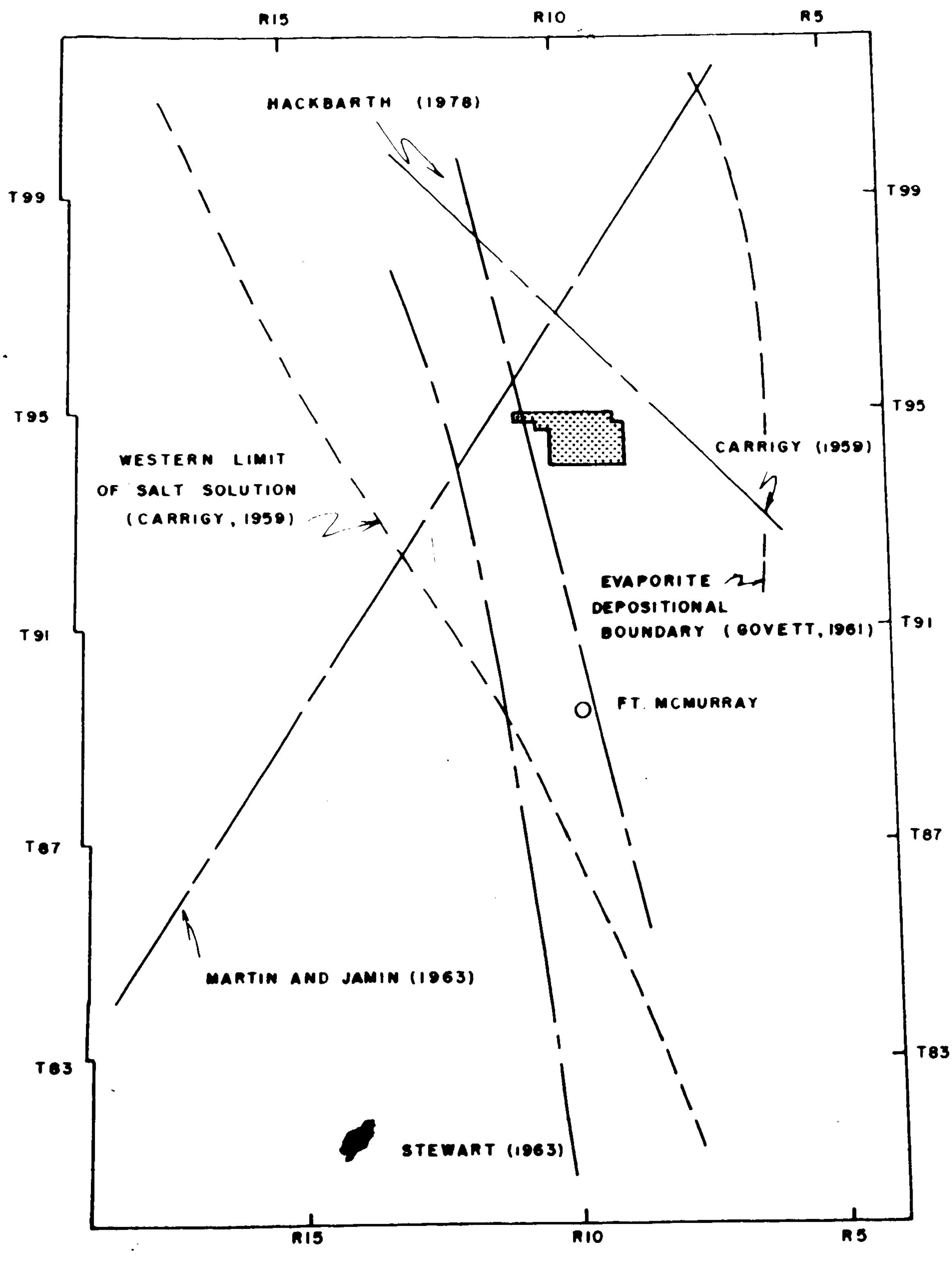


FIGURE 2.3: REGIONAL FAULT TRENDS

Point Evaporite leaching, Pre-Cretaceous erosion and deep-seated Precambrian faulting. This faulting was related to erosional ridges on the Devonian-Cretaceous unconformity.

Norris (1963) compiled detailed lithologic and biostratigraphic information on each Waterways Member and identified a south-southwest structural trend. This trend was incompatible with the regional southwesterly dip and thus minor flexures were considered unrelated to the monocline. Norris (1963) also identified regional southwesterly post-Cretaceous tilting and faulting.

Martin and Jamin (1963) identified various erosion resistant scarps or cuestas which were thought to be crosscut by a major deep-seated northeast fault pattern. The movement of the northern block was considered to have been northeasterly relative to the south block (Figure 2.3). The scarps were attributed to both surface erosion and warping over successive steps of the collapsed Elk Point Evaporites. All cuestas trend north-northwesterly. Martin and Jamin (1963) also suggested local valley trends were fault-controlled, however, they did not account for the origin of the faulting.

Hackbarth (1978) and Hackbarth and Nastasa (1979) also proposed faulting throughout the Athabasca region. They named the Sewetakun fault which strikes subparallel to the Athabasca River, southeasterly from Ft. MacKay to Ft. McMurray (Figure 2.3). Hackbarth (1978) cited the presence of 83 metres of offset between adjacent wells in the Precambrian in addition to gravity map trends, low hydraulic heads, coincidence of the salt solution edge and intense structural deformation of rock units along the trend, as evidence. Hackbarth and Nastasa (1979) proposed a second west-northwest trending fault and a western downthrow for the Sewetakun fault. Regional paleodrainage was further attributed to pre-existing fault trends.

Jointing is another large scale regional structural feature. Babcock (1975) conducted joint surveys along the Athabasca River and reported two dominant joint systems (four sets) in the Moberly Member. Although both systems were reportedly well developed, Babcock (1975) emphasized that both may not appear in every outcrop. A north-south-east-west system was found to dominate the less obvious north-northwest/east-northeast system. Numerous random fractures were also observed.

Babcock (1975) also noted that the secondary system paralleled the Cordillera and attributed its development to tectonic stressing associated with the Tertiary Laramide orogeny. He also stated that both systems displayed parallelism with Precambian basement structures. The overall continuity of joints was considered to represent a widespread, uniform stress system. Sinha (1976) also provided local structural information, however it was not consistent with the findings of Babcock (1975).

Babcock and Sheldon (1976) correlated earlier joint surveys with aerial photographs. They observed that sinkholes north of the study area were aligned with the solution edge of the Prairie Evaporite. They also inferred that Paleozoic drainage, salt solution and structural flexing are processes that are directly related.

Williams, Stimpson, Patching and Jeremic (1980) also reported on Waterways joints. They concurred with Babcock's (1975) findings and added roughness, waviness and planarity data. They found roughness indices did not correlate well with any other geological or engineering parameter and that roughness was difficult to characterize due to local textural variations. Williams et al (1980) noted joints were predominantly vertical and rarely extended across two adjacent lithologies. They did not report any occurrences of joint displacement or shear. Mathews, Rawlings and Bharti (1980) added that regional faulting may be difficult to distinguish from subsidence effects.

Finally, the nature of the Devonian-Cretaceous unconformity and its associated paleotopography is considered. Gorrel (1974) recognized two influences on Devonian relief, that of Pre-Cretaceous channel scouring and Prairie Evaporite solution subsidence. Carrigy (1959) also recognized several episodes of subaerial exposure and suggested the resultant topography was structurally controlled by Prairie Evaporite removal. Norris (1973) reported regional westward tilting of approximately 2.8 metres per kilometre during the Devonian-Cretaceous hiatus. Martin and Jamin (1963) also suggested tilting of less than 3 metres per kilometre.

In general, Waterways paleotopography is complex and highly sculpted (Figure 2.4). Norris (1973) illustrated slopes as great as 76 metres per kilometre with relief up to 152 metres. The regional northwesterly trend represents the erosion-resistant edges of various subcropping members.

Martin and Jamin (1963) identified three primary influences upon paleotopography:

1. regional Pre-Cretaceous tilting to the southwest of approximately 3 metres per kilometre.
2. localized warping forming basins with no traditional strike direction. Flank dips of 1°-20° and amplitudes up to 76 metres were measured. All deformations were attributed to solution removal of the Elk Point Evaporites.
3. Precambrian and Paleozoic faults striking northeasterly and thought to be due to regional tectonic activity.

They also depicted two principal paleodrainage basins. The basins were separated by an erosion-resistant ridge south of

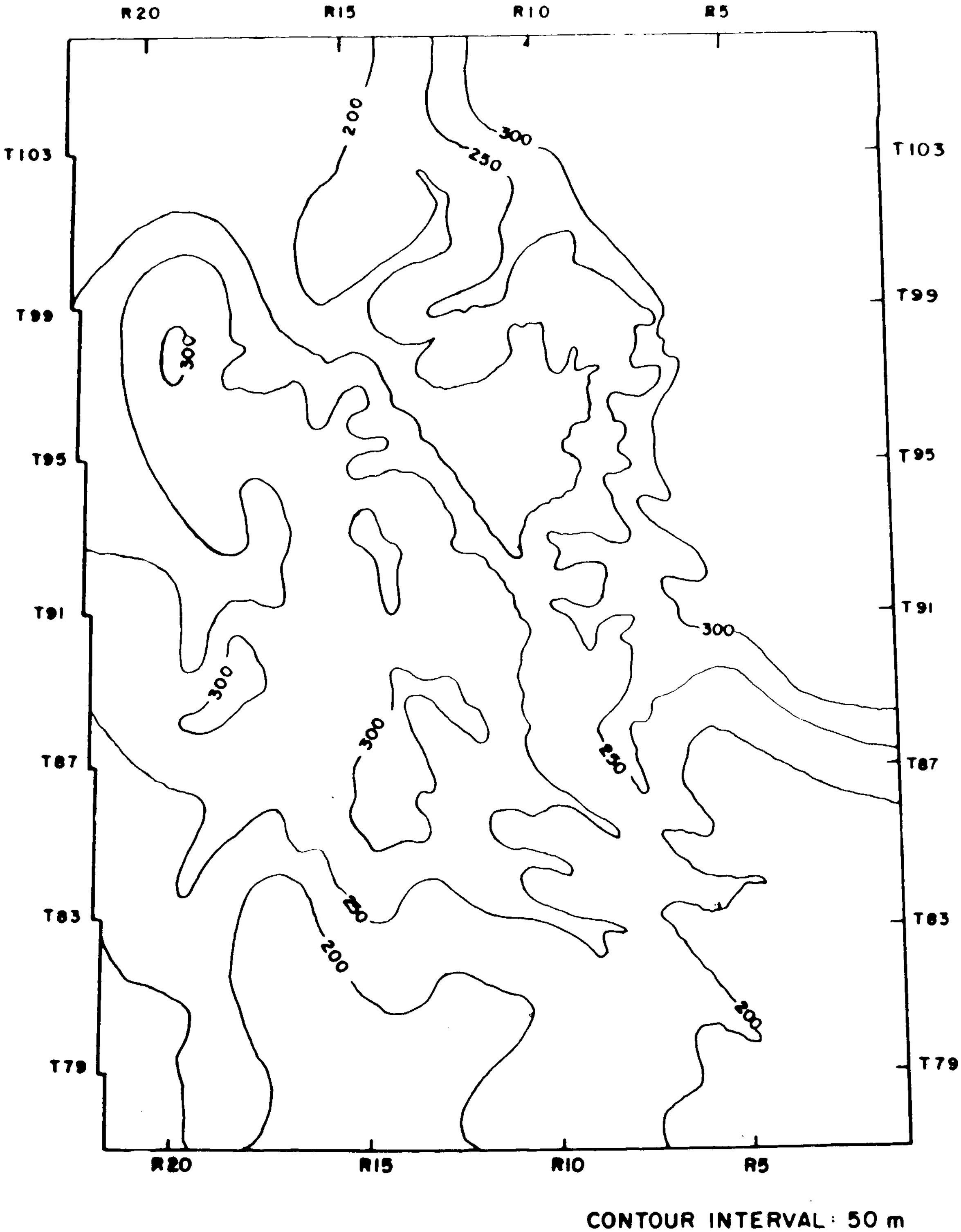


FIGURE 2.4: REGIONAL PALEOZOIC STRUCTURE (after Martin and Jamin, 1963)

SANDALTA which effected northerly paleodrainage at the SANDALTA locale. These channels were considered by Stewart (1963) to exercise a major influence upon Cretaceous sand deposition.

In summary, the structural history of the Waterways includes episodes of regional jointing, faulting and subsidence. Tectonic folding is not generally recognized. The upper surface displays a deeply incised, complex paleotopography which has been affected by major erosional and subsidence occurrences in addition to surface solution. The character and degree of development of the karst is poorly documented.

2.3 Hydrogeology

Hydrogeologic studies completed by Gorrel (1974), Hackbarth (1977, 1978, 1980), Hackbarth and Nastasa (1979) and Ozoray, Hackbarth and Lytviak (1980) have contributed to a preliminary understanding of the Athabasca hydrogeology. Site specific studies may have been conducted throughout the mined areas, however the results of such studies are not generally available.

In their 1974 regional hydrogeologic study, the Oilsands Environmental Study Group established that Devonian depressions in the Bitumount area acted as either subsurface drainage basins or as vertical hydraulic conduits. Numerous sinkholes were identified and a prominent collapse structure was defined at the boundary between Townships 94 and 95, Range 9 (the northern boundary of the SANDALTA lease). An upward regional hydraulic gradient through the Middle and Upper Devonian was identified and both basal and post-Devonian aquifers were established. A well defined karst topography and fluviodrainage pattern were also recognized.

Hackbarth (1977) provided a more detailed regional hydrogeologic overview. He defined three regional flow systems employing the Precambrian crystalline rocks as the hydrogeologic basement. The three systems included:

1. Cretaceous - ternary system
2. Upper Devonian system
3. Middle and Lower Devonian system

Hackbarth (1977, 1978) further indicated that groundwater flow in the Cretaceous system is structurally controlled. Recharge apparently occurs in surficial muskeg-filled low lying areas and discharge by major streams and rivers. Hydraulic heads were everywhere less than hydrostatic due to a proposed horizontal flow regime.

Upper Devonian flow regimes are controlled by two dominant factors according to Gorrel (1974), Hackbarth (1978) and Hackbarth and Nastasa (1979):

1. An inverse hydraulic gradient between the

Lower Devonian and Lower Cretaceous systems. That is, higher hydraulic heads are encountered in the Methy Formation than in the McMurray Formation. An upward flow direction is thus imposed across the Waterways Formation.

2. A major Pre-Cretaceous fault, named the Sewetakun fault, subparallel to the Athabasca River. The fault supposedly provides hydraulic communication between the three groundwater systems and permits vertical flow or drainage in the immediate fault vicinity.

Vertical flow is supported by surface saline springs originating in the Methy Formation and the potential for a vertical permeability anisotropy identified in Section 3.6.4. Ozoray, Hackbarth and Lytviak (1980) identified various saline springs and commented on the hydrogen sulphide odour and groundwater chemistry of each. They suggested that permeability within the Upper Devonian may be structurally controlled and noted that collapse ponds near McClelland Lake are roughly orthogonal. This feature suggests preferential corrosion or kluftkarren may have developed (see Section 4.1.2).

Waterways permeability was not measured by Williams (1980) in his testing program, however the very low porosities reported suggest that primary permeabilities are negligible. Instead, secondary fracture permeability is expected to characterize the rock mass. GCRI (1981) reported intact permeabilities less than 10^{-13} m^2.

It is emphasized that rock mass permeability is stress-dependent and cannot be meaningfully measured in unconfined core. Moreover, the in-situ permeability will be influenced by regional stress state fluctuations such that changes in the stress field will affect the secondary permeability of fractures, solution pipes or other karst features.

Hackbarth and Nastasa (1979) reported Waterways conductivities in the range of 10^{-5} to 10^{-8} cm/sec. They considered the formation to act as an aquitard, thereby inducing high hydraulic heads in the basal McMurray water sands. Hackbarth and Nastasa (1979) further established a solution leach edge extending from Township 92, Range 14 to Township 103, Range 21. They stated evaporite solution had been most intense east of this edge and had caused a general subsidence of roughly 100 metres. The evaporite sequence thins to zero eastward. The resulting subsidence was considered to contribute to increased secondary permeability.

2.4 Geotechnical Properties

Few studies have assessed Waterways geotechnical properties and behaviour. Various consultants reports have included basic rock mechanics evaluations, however in general, Williams (1980) was the first to undertake a comprehensive Waterways testing program.

Williams' (1980) test program was conducted upon block samples obtained from outcrop and core samples retrieved during drilling. No in-situ testing was conducted. Williams (1980) conducted standard index property tests and completed the following strength and deformability evaluations on both intact rock and rock mass discontinuites:

1. unconfined uniaxial compression
2. direct pull tension
3. four point bending tension
4. Brazilian tension
5. triaxial compression
6. double shear
7. rock deformability
8. ultrasonic P-wave velocity
9. impact toughness
10. point load
11. slake durability
12. swelling

Three dominant lithologies were tested; massive crystalline limestone, nodular limestone and shaly limestone. Four sublithologies of both the massive and shaly limestones were identified and the nodular limestone was assigned two sublithologies. No attempt has been made to align present lithologic descriptions with those of Williams (1980). Williams (1980) concluded that rock lithology exercised a major influence upon engineering behaviour. His most significant findings included the following:

1. Intact uniaxial compressive strength decreases with increasing argillaceous content. The presence of clay was considered proportional to the absence of cement.
2. Tensile strength is anisotropic in the interbedded and nodular lithologies. Tensile strength parallel to bedding is greater than that perpendicular to bedding. Water saturation effects a measurable loss of tensile strength.
3. Intact triaxial compressive strength was greatest in the massive crystalline limestones at all stress levels.
4. Concave Mohr envelopes indicate the propensity of various lithologies for plastic behaviour at high confining stresses.

5. Cohesive strength is anisotropic and low for all lithologies.
6. Deformabilities are moderately stiff to very stiff for all lithologies.
7. Time-dependent deformation is negligible at low confining stress.
8. Argillaceous lithologies are readily weathered.
9. All lithologies are resistant to slaking.
10. Unconfined axial swell of up to 9% may occur in the argillaceous lithologies.
11. Weathering originates in formation joints and progresses inward through the intact rock. Bitumen coatings inhibit joint weathering.
12. Primary limestone porosities are negligible.
13. Sonic wave velocity correlates well with sample density.

Specific engineering properties are summarized in Figure 5.1.

3. GEOLOGICAL INVESTIGATION

3.1 General

The geological component of the study involved detailed descriptive logging of 123 core sections retrieved from the SANDALTA lease during winter drilling of 1980 and 1981. All laboratory work was performed in GCRI's Calgary warehouse during the period June to October, 1981. All conclusions have been based upon features observed at SANDALTA.

3.2 Local Stratigraphy

In the study area, over 200 coreholes have penetrated the McMurray formation and cored the Devonian rock mass. Approximately 3000 metres of Devonian core was retrieved from minimum well spacings of approximately 400 metres. Although the maximum depth of Paleozoic penetration at any particular well is far less than the thickness of any one Waterways Member, relief on the Devonian-Cretaceous unconformity has permitted mapping of 100 metres of stratigraphic section. On the basis of this section, the Devonian rock mass subcropping at SANDALTA is thought to represent the Moberly Member. In addition, much of the deeper core is believed to represent the Christina

Members. The uppermost Mildred Member is thought to have been completely eroded. Norris (1981) concurred with this interpretation and added that outcrops of the lower Calumet and Firebag Members have been observed along the Athabasca River downstream of SANDALTA. Subcrop maps (Figure 3.1) illustrate the expected stratigraphy in the Ft. McMurray region.

3.3 Core Lithologies

3.3.1 General

Gross lithologic distinctions have been made primarily on the basis of texture, colour, clay content, grain size and mineralogy. Additional observations were made concerning inclusions, weathering, solution, bitumen stain, fossil content, induration, porosity and fracture characteristics. A summarized descriptive log of each core section is included in Appendix A.

Four marine and two non-marine lithologies were distinguished in the Moberly-Christina core. Several sublithologies were also identified and are presently described.

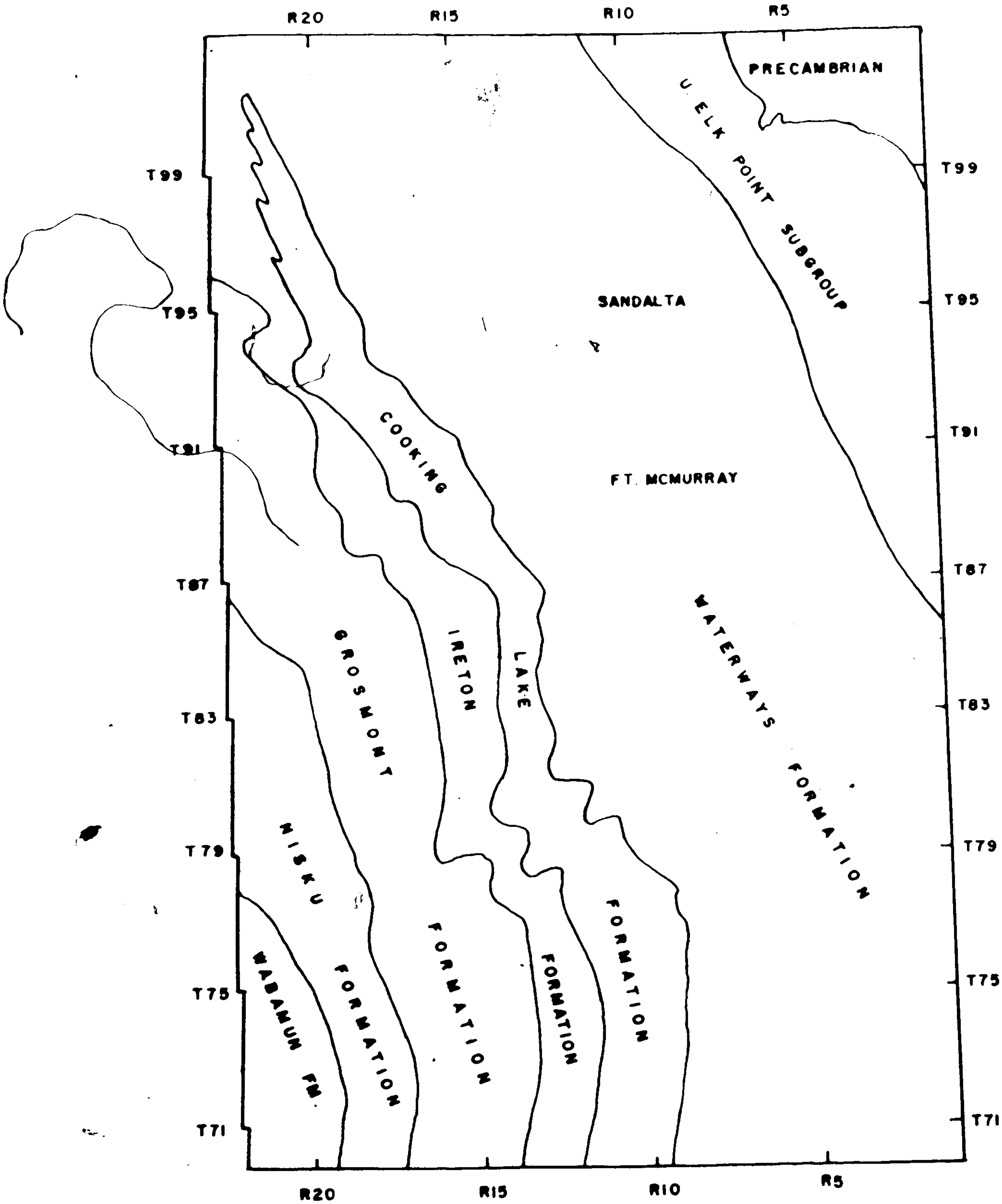


FIGURE 3.1: REGIONAL PALEOZOIC SUBCROP (after Stewart, 1963)

3.3.2 Rock Type A - Argillaceous Limestones

Three argillaceous limestone sublithologies were identified during the core study. Collectively, they comprised 60% - 70% of the total observed footage. Each sublithology represents a unique depositional environment within the regional marine platform. It is emphasized however that although each sublithology is texturally unique, it is expected a number of intermediate lithologies exist between the extreme cases. This arises from the transitional nature of the marine environment. More specifically, one may consider the transition from sublithology I to III to be a consequence of continuous deepening in water.

The three sublithologies are:

I - massive, crystalline to marbly or mottled argillaceous limestone

II - nodular argillaceous limestone

III - finely interbedded limestone and micrite

Sublithology I (massive crystalline to marbly argillaceous limestone) was the most common rock type observed. It is characterized by an overall low clay content, generally less than 30%, and a mottled or marbly texture (Plate 3.1). This texture is considered to represent poorly defined bedding. Post-depositional processes such as differential compaction, consolidation and

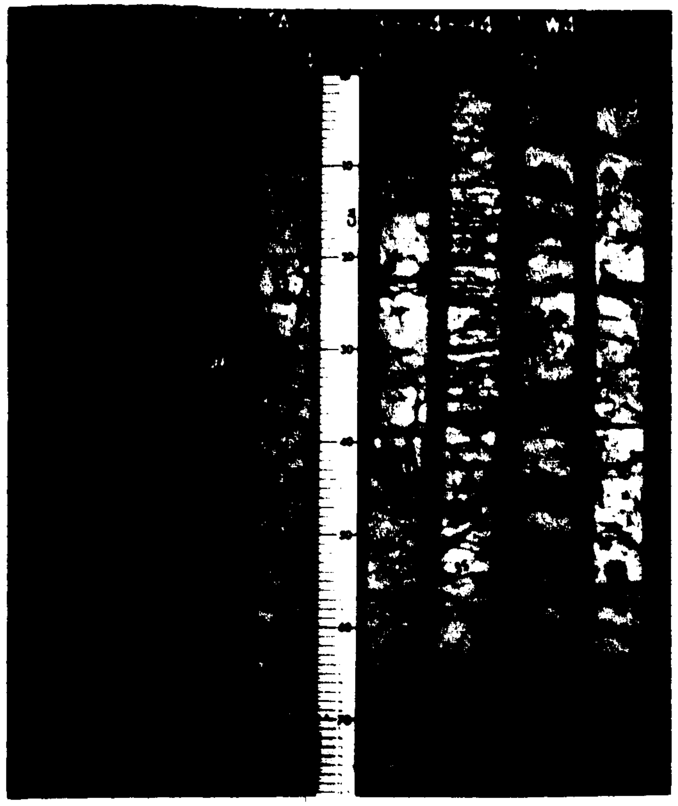


Plate 3.1: Rock Type A-Massive Crystalline/Marbly Argillaceous Limestone (CH.174).

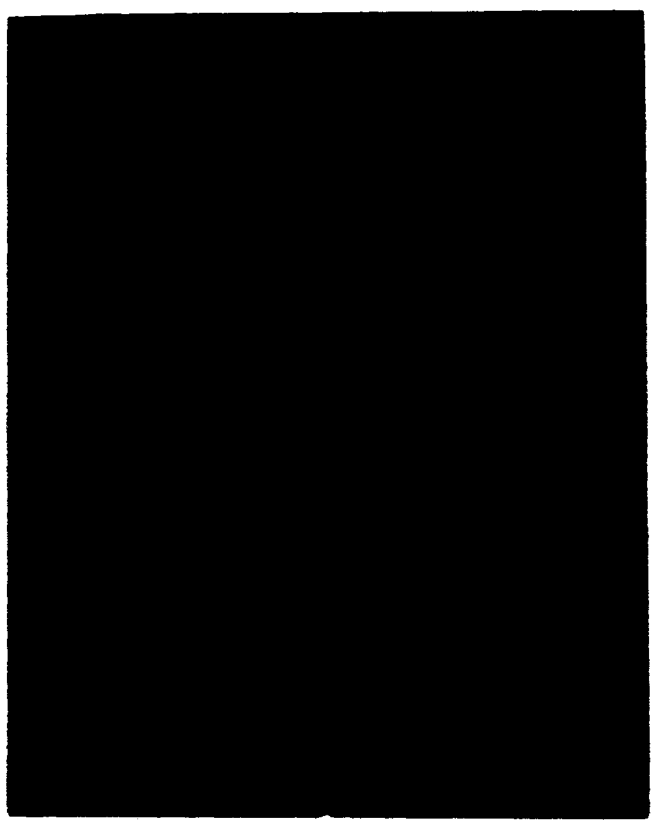


Plate 3.2: Pyrite nodules (CH.88)

bioturbation are also believed to have contributed to the mottled texture.

Colour varies from grey or white in the massive microcrystalline variety to buff in the upper weathered zone. Interbedded micrite is commonly olive to grey in colour. Reworked lime muds infilling solution voids are characteristically light green.

The massive to mottled limestones are generally hard and well indurated. Fresh core sections display a dense, brittle character. The carbonate component is microcrystalline whereas the argillaceous component is predominantly fine grained carbonate mud or micrite. The argillaceous component does not represent transported continental detritus, but rather suspended particles from within the marine environment.

Despite their mottled texture, these limestones display a well defined subhorizontal bedding attitude (Plate 3.1). Apparent dips rarely exceed 10° to the normal to the core axis, although steeply dipping beds were occasionally observed. These features are discussed individually in Section 3.6.4. Secondary structures include subvertical joints and rare flame structures.

Mineralogic studies by McDonald (1947) indicated that a common iron sulphide is marcasite (FeS_2), a polymorph of pyrite. Marcasite and pyrite are dimorphous and distinguishable only on the basis of crystal form. They are not easily differentiated in hand samples, thus all descriptive logs refer to this sulphide as pyrite. According to Berry and Mason (1959), marcasite is found most often in supergene locations where it has formed at low temperatures from acidic solution. It is usually found in sedimentary rocks such as limestone and commonly as concretions or fossil replacements. Pyrite, which is more stable, apparently forms under higher temperature and lower acidity conditions. In the 'present study, marcasite was commonly found as a replacement lining small solution pipes, joint fractures and on submarine hardground surfaces. Random disseminated grains were also observed, however these were quantitatively insignificant. Small nodules (Plate 3.2) were also commonly observed.

Another common mineral occurrence was siderite. Siderite is an iron carbonate ($FeCO_3$), commonly yellowish brown to reddish brown, found in sedimentary rocks as a concretion or hydrothermal deposit. Its presence in conjunction with marcasite suggests it may have originated during hydrothermal replacement of the host limestone by an iron-rich solution. The occurrence of siderite was commonly in the form of small (mm) spheres or sphaerosiderites (Plate 3.3). This form supports a concretionary origin. The origin of marcasite and siderite are further discussed in Section 3.4.

GCRI (1981) conducted clay mineralogy tests that

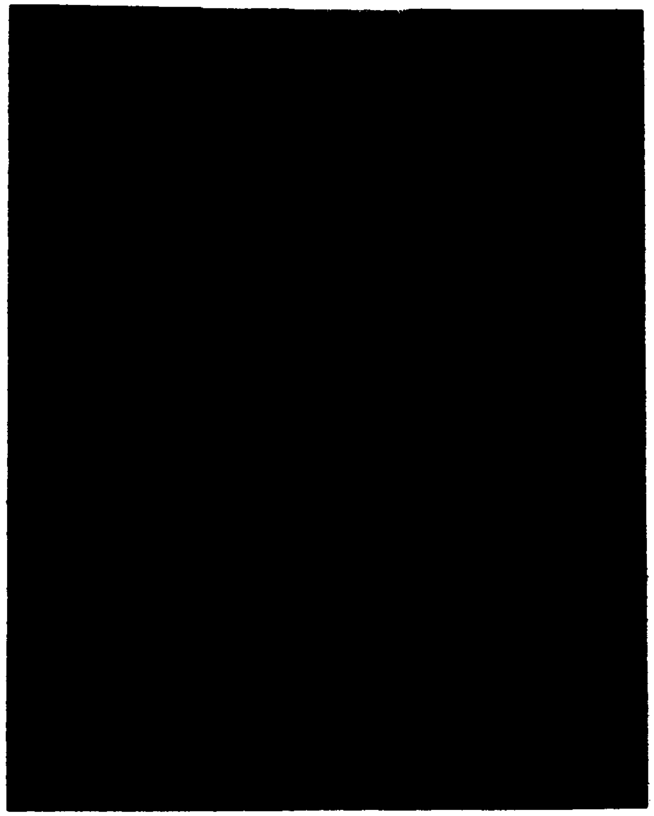


Plate 3.3: Sphaerosiderites (CH. 135)

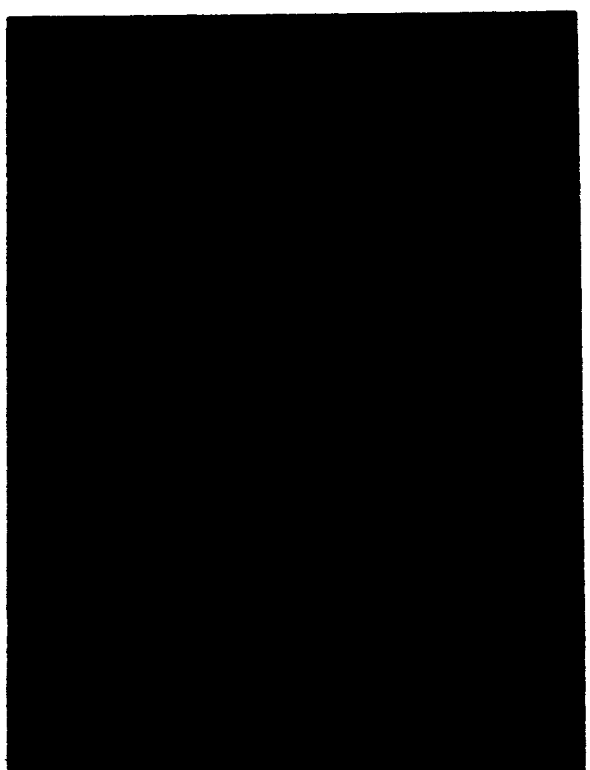


Plate 3.4: Bitumen Stained Subvertical Fracture (CH. 163)

revealed an illitic dominance of 60%-70% in the clays and micrites of the argillaceous limestones. Variable amounts of kaolinite (20% - 40%), chlorite (5% - 15%) and mixed layer clays were also recorded. X-ray diffraction tests conducted during this study (Appendix C) agree with GCRI's information and help distinguish the origin of the various clay components (see Section 4.3.3). The absence of smectite clays such as montmorillonite is presently noted.

Fossils are abundant throughout rock type A, however less so in the argillaceous units. Dominant species include brachiopods, gastropods, cephalopods, pelecypods and domed or branching stromatoporoids. Brachiopods were observed in distinct subhorizontal beds as opposed to a random distribution. These beds are believed to have represented stable submarine surfaces upon which organisms could thrive. One may relate the cessation of indigenous carbonate production to the concurrent emergence of various benthonic fauna. Moreover, the occurrence of marine hardground surfaces is a common feature of the argillaceous limestones. Stoakes (1980) refered to hardground surfaces as "intraformational synsedimentary lithification surfaces formed in a submarine setting". They are thought to develop during sustained periods of non-deposition or diastems, where a well defined submarine floor was permitted to develop. No erosional processes were active and the resulting surface is very dense, well cemented and commonly fossiliferous. In section, hardgrounds are readily identified on the basis of their dark colour, sparitic matrix and hard, dense texture. Microscopic examination may also reveal the presence of characteristic worm borings, crinoid fragments or algal coated grains (Dolph, 1981). Hardgrounds are useful stratigraphic time lines.

Porosity in the argillaceous limestone is limited to secondary fracture and solution voids. Primary intergranular porosity is negligible. GCRI (1981) reported primary porosity values less than 0.5%. These are likely due to random vuggy or fenestral voids. More commonly, fossil replacements or fracture and solution openings provide secondary porosity. Due to the stress level dependence of fracture and solution void gape, accurate porosity measurements cannot be conducted on unconfined core.

Rock mass permeability is also stress level dependent and cannot be meaningfully measured in unconfined core. It is apparent that the permeability of the argillaceous carbonates is structurally controlled by fractures and solution pipes. Moreover, it is believed that the influence of stress on permeability has led to a significant vertical anisotropy. The opening of formation fractures at in-situ stress levels may contribute to vertical permeabilities that are several orders of magnitude greater than horizontal (see Section 3.6.4).

The presence of bitumen stain throughout fracture porosity is common in rock type A. The staining is primarily restricted to vertical or inclined fractures (Plate 3.4), which supports a vertical permeability anisotropy and a normal principal stress field (see Section 5.4.2). The stain is also useful in establishing the stress history relative to the time of bitumen infiltration (see Section 4.3.2).

Weathering effects were usually observed in the upper 1-2 metres of the Devonian profile immediately below one of several intraformational unconformities. Discoloration due to oxidation, softening, and a loss of texture characterize the weathering effects. Widespread paleosols were not encountered, however non-marine basal McMurray alluvium was abundant. The alluvium occurs in a sporadic distribution of Devonian lows and north-south fluvial channels (see Section 4.2.1). Most often, a well defined weathering profile did not exist and the Paleozoic surface was highly scoured (Plate 3.5).

Sublithology II (nodular argillaceous limestone) is very similar to sublithology I in mineralogy and most physical properties. The texture is however, substantially different. Sublithology II represents a transitional facies

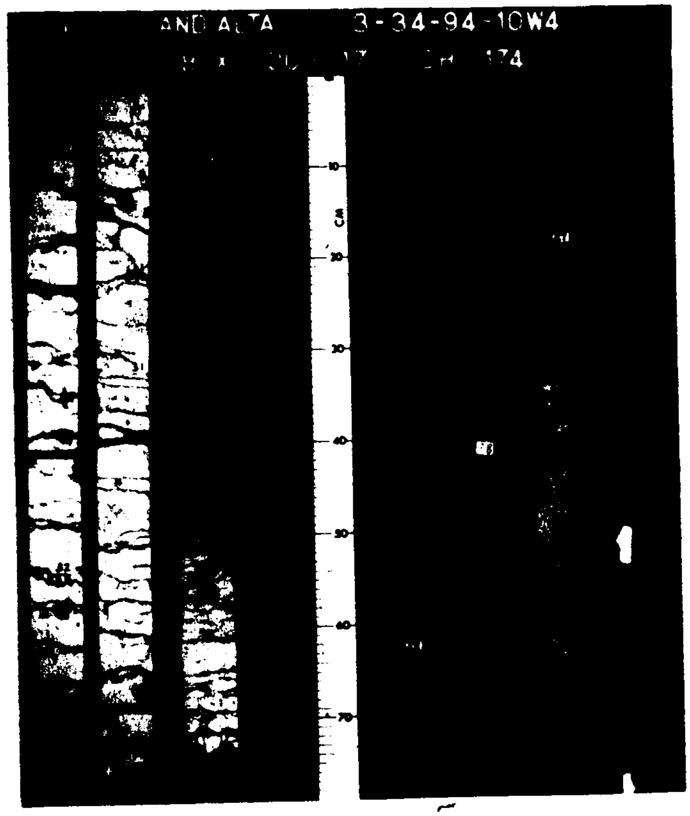


Plate 3.5: Scoured Devonian-Cretaceous Contact (CH.174)

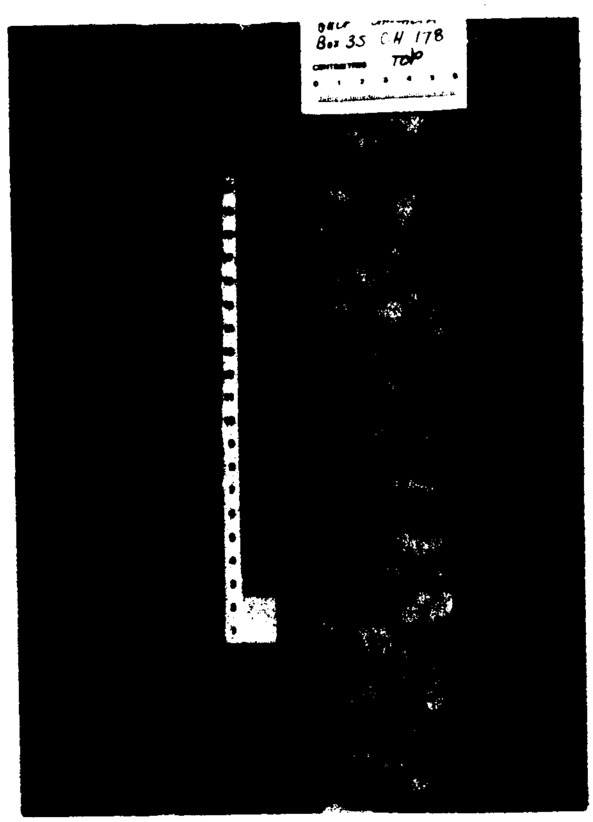


Plate 3.6: Rock Type A - Nodular Argillaceous Limestone (CH.178)

between the well defined interbedded units and the previous microcrystalline textures. It is thought that carbonate nodules form soon after deposition as a product of concretionary action and differential compaction. The nodules often grade into the surrounding groundmass and display an irregular shape and size. They are commonly elongated in the subhorizontal direction and typically 2-8 cm in length (Plate 3.6). This elongation supports overburden compression prior to complete lithification. These nodules are distinguished from the erosional intraclasts of rock type C. Williams (1980) suggested the nodular textures were due to fragmentation, transportation and redeposition during submarine slumping. No evidence of slumping or disturbance was noted during the present study and these textures are considered to be syngenetic.

The nodular lithologies are generally well-indurated. A hard, brittle nature is characteristic, however in outcrop, differential weathering creates a rubbly appearance. All carbonate is microcrystalline whereas the argillaceous content is carbonate mud or micrite. Argillaceous content rarely exceeds 50% (GCRI, 1981). Colour varies from grey to white for the massive nodular variety to buff in the weathered horizons. Secondary structures are limited to subvertical joints.

The presence of siderite and marcasite are noted as in the marbly argillaceous limestones of sublithology I.

Clay mineralogies are also consistent with those of sublithology I, displaying a strong illitic dominance with minor kaolinite, chlorite and mixed-layer clays.

A lack of stable hardground surfaces and a high argillaceous content are thought to be responsible for the absence of fossils in the nodular limestones.

Primary porosity is again very low as secondary porosity predominates. Permeability is structurally controlled as in sublithology I and is also expected to be vertically anisotropic.

The well defined bedding of sublithology III (finely interbedded limestone-micrite) provides the most information about the marine environment. It suggests a short term cyclic pattern of carbonate-micrite production resulting in rythmic limestone-clay sequences (Plate 3.7). The period of depositional cycles is estimated to be seasonal or yearly.

Color alternates from the grey-white carbonate to the darker grey or olive micritic interbeds. Overall clay content commonly exceeds 50%.

Secondary structures again include subvertical joints. Solution and weathering features are discussed in Chapter 4. One additional feature of this sublithology is small scale (cm) boudinage. This phenomenon is discussed in Section 3.6.1.

Sublithology III maintains the same bulk and clay

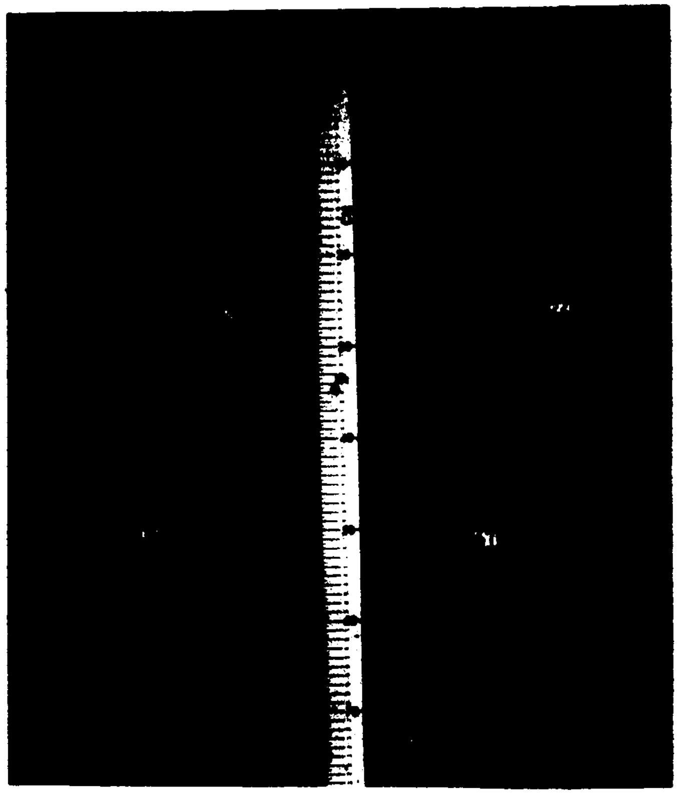


Plate 3.7: Rock Type A - Finely Interbedded Limestone-Micrite (CH.194)

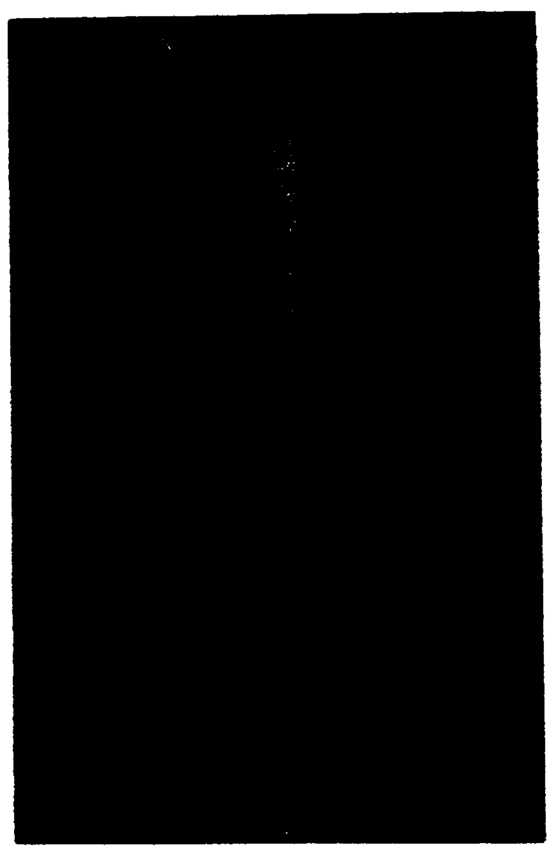


Plate 3.8: Rock Type B - Calcareous Shale (CH.131)

mineralogies reported for the two previous sublithologies. Moreover, the three sublithologies are thought to differ only in texture and clay content. Other bulk properties are considered to be common.

3.3.3 Rock Type B - Calcareous Shale

Calcareous clay shale units comprised approximately 20% - 25% of the observed core and dominated the lithology below 240 masl which is thought to be the Christina Member. The shales do not correlate well in section due to their lack of lithologic distinctiveness. They grade both laterally and vertically into the argillaceous limestones of rock type A, however they do represent a distinct change in depositional environment. Some shale-carbonate contacts were very abrupt and are thought to represent a more rapid change in environment (Plate 3.8).

The thickness of the shale units varied considerably and the author arbitrarily imposed a 0.5 m minimum thickness. Beds less than 0.5 m were considered interbeds of the argillaceous limestone. Only beds greater than 0.5 m are identified on the study logs.

The calcareous shales are generally massive, fissile and well cemented. Distinguishable bedding planes were rarely identified, however a subhorizontal fissile character is discerned. Occasional interbedded carbonate lenses may also be observed. Although much of the fissility is due to dessication and handling, the undisturbed marine floor environment is considered to be primarily responsible for the laminar character.

Authigenic calcareous cementation is thought to have occurred during consolidation. Rare non-calcareous shales were observed, however none were found at depth in the section and they were associated with non-marine sources. It is thought that all marine shales exhibit authigenic calcareous cementation.

Mineralogically, the calcareous shales are predominantly illitic. This is contrasted to the illite-kaolinite mineralogy of the basal McMurray clays in Section 4.3.3. In addition to the clay mineralogy, marcasite was also observed. Again, marcasite most commonly occurs as fossil casts, hydrothermal replacements and disseminated grains. It is not detrital in origin.

Fossils are rare in the shales. A highly micritic or turbid environment "chokes" many marine organisms thereby preventing continuous production. Brachiopods are among the hardiest and are found scattered throughout the shales.

The development of hardground surfaces is not as extensive as in the argillaceous limestones of rock type A. This is believed to be related to the higher sedimentation rate of micrite relative to calcium carbonate.

In-situ shale porosity is expected to compare with the dense argillaceous limestones. All voids are secondary in origin. There is no solution or vugular porosity in this rock type. Again the stress level dependence of porosity and permeability demand in-situ measurement. Permeabilities are expected to display significant structural anisotropy. Hydraulic communication is achieved through the regional joint system and is not generally affected by bedding features.

The marine shales weather readily when exposed. Their susceptibility lies in the dissolution potential of the calcareous cement. Discoloration and general softening are the characteristic features of weathered shale.

Bitumen staining may also be observed where subvertical fracture permeability exists.

3.3.4 Rock Type C - Limestone Intraclast Breccia

This unit comprised less than 10% of the observed core footage and is genetically related to the biohermal limestones of rock type D. It is readily identified by its characteristic disturbed appearance and distinct brecciated texture (Plate 3.9). The subrounded to angular limestone clasts of the framework (20-30%) are supported by a grey argillaceous matrix (70-80%). Cement is calcareous. The fresh, angular nature of the clasts suggest that minimal transportation and reworking has occurred. Furthermore, the

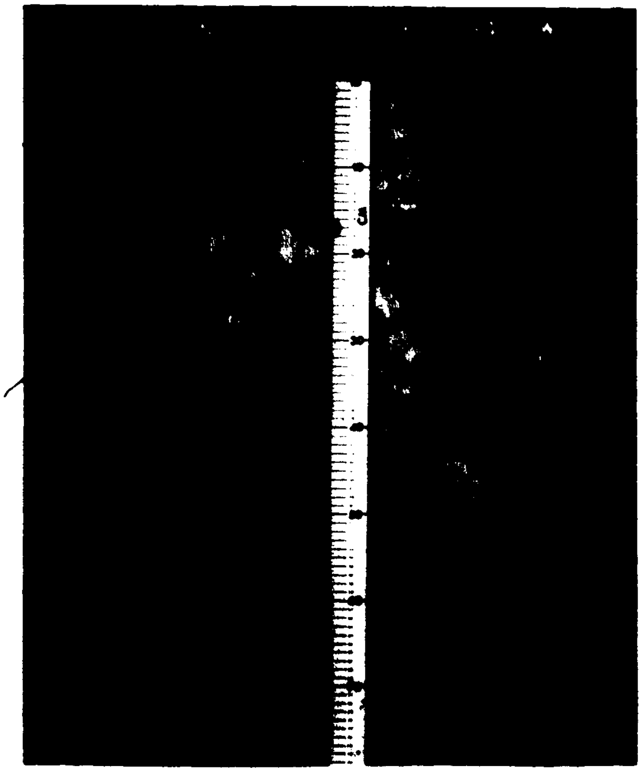


Plate 3.9: Rock Type C - Limestone Intraclast Breccia (CH.88)

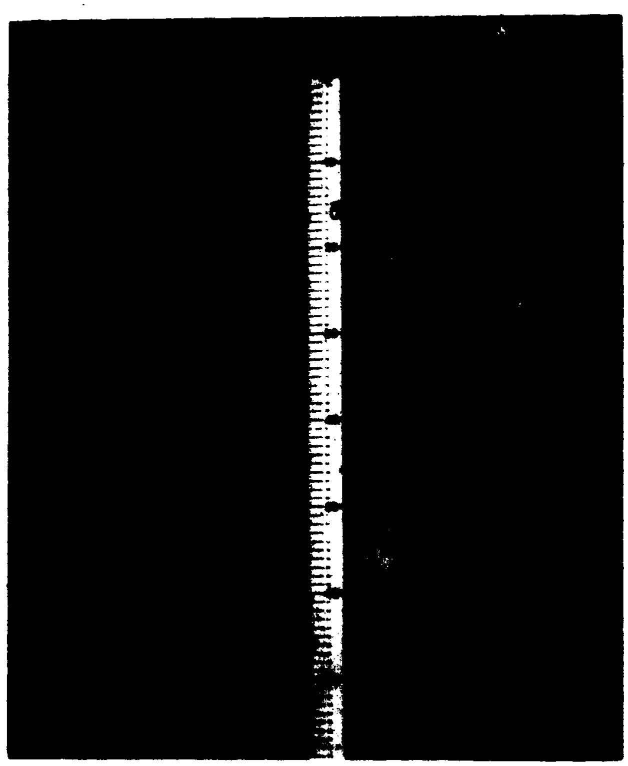


Plate 3.10: Post-Depositional Collapse Breccia (CH.88)

constant intraclast mineralogy supports a locally derived source rock. In Section 3.4.2, the intraclast texture is related to subaerial wave processes acting upon small patch reefs within the depositional basin. It is emphasized that the breccias of rock type C are not post-depositional collapse or solution features. Rather, they are the product of unique syndepositional mechanisms which are related to wave-produced fragmentation of lithified rock (see Section 3.4.2). One must clearly distinguish between the post-depositional collapse structures illustrated on Plate 3.10 and the syndepositional fragmentation breccias described herein (Plate 3.9).

The limestone intraclast breccias are commonly less than 2 metres thick and immediately overlie the biohermal limestones of rock type D. They are generally well cemented, but are expected to weather readily upon exposure. Clay content is high and thought to exceed 50%.

The colour of the intraclasts is commonly white to grey whereas the matrix is grey to olive. Occasional black bitumen stains were observed. The bitumen is thought to be locally derived (see Section 4.3.2).

Bulk mineralogy is dominated by the carbonate and clay species of the framework and matrix. Minor quantities of siderite and marcasite were observed. Clay mineralogy was again predominantly illitic with minor kaolinite, chlorite and mixed-layer clays (GCRI, 1981). Fossils are non-existent due to the high energy depositional environment.

Secondary structural features are limited to random fractures. A well defined fracture pattern was not observed. Some apparent shrinkage textures were observed, suggesting that the deposit may have existed in a semi-plastic state prior to coring.

Minimal interparticle porosity is thought to exist, however no test measurements are available. Secondary porosity exists in the form of fractures and minor solution voids. Permeability is also unmeasured however thought to be structurally controlled by fractures. Due to the random nature of the fracture pattern, rock type C is not expected to display the permeability anisotropy found in rock types A and B.

3.3.5 Rock Type D - Biohermal Limestone

Approximately 10% - 15% of the observed core footage was biohermal limestone. It is readily distinguished from all other units on the basis of its porous, biolithic texture and heavy bitumen stain (Plate 3.11).

According to Harrison (1982), the term bioherm suggests a genetic development of organic carbonates as opposed to the stratigraphic definition of a biostromal

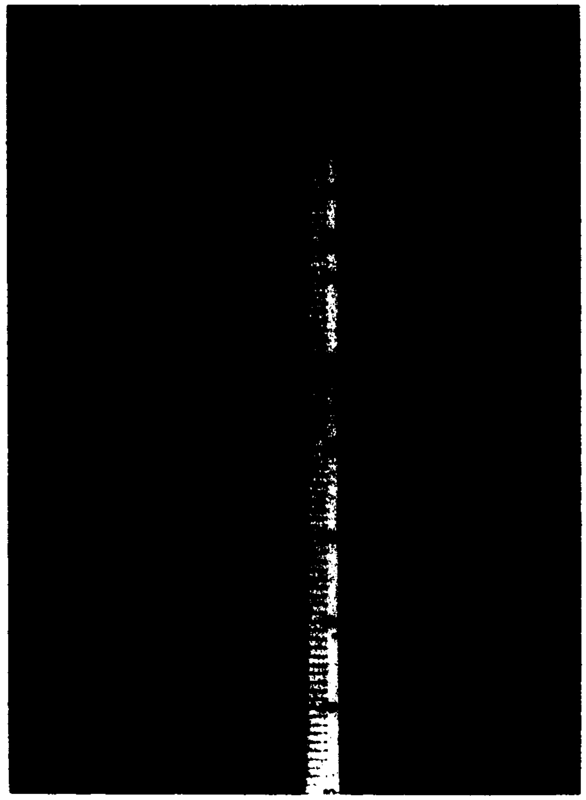


Plate 3.11: Rock Type D - Biohermal Limestone (CH.13)

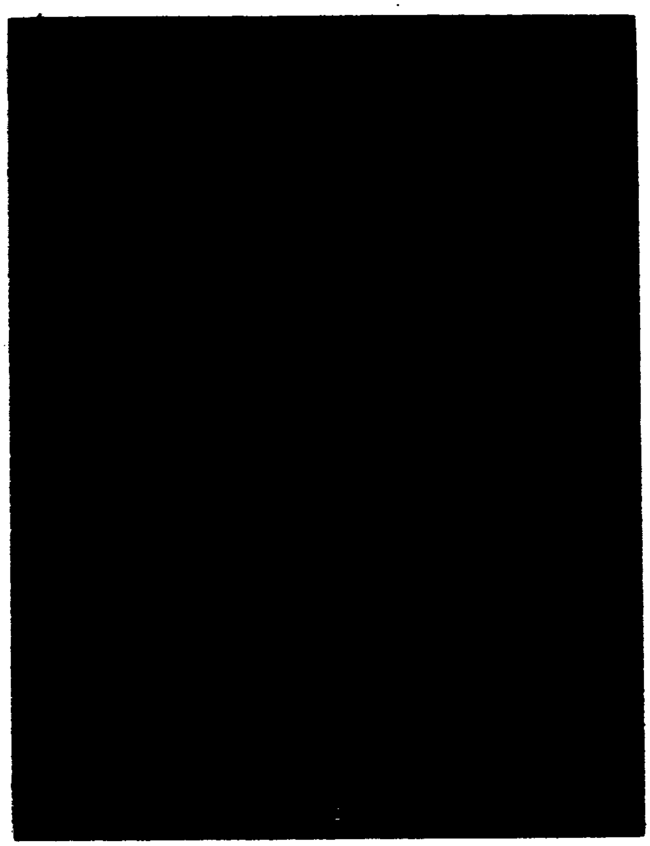


Plate 3.12: Rock Type E - Uncemented Quartz Sands (CH.93)

buildup. Biohermal buildups possess a solid organic framework built by organisms capable of producing a wave resistant structure. Biostromal buildups may or may not form a rigid framework and are most commonly topographic accumulations of organic skeletal debris. The rigid biolithic framework of rock type D clearly defines a genetic biohermal deposit. There is no evidence of post-lithification disturbance or debris cementation. All structure is thought to be syndepositional.

The biohermal units are generally less than 2-3 metres thick. They are consistently located above 240 masl and thus are thought to be restricted to the Moberly Member.

The pelletal mounded fabric is relatively well developed and displays a strong subhorizontal attitude. Tabular or branching stromatoporoids and thamnoporoid corals comprise the skeletal framework and are partially supported by a micritic matrix. Cement is calcareous.

The biohermal limestones are generally well indurated. Colour is grey to white with a heavy black bitumen stain in the biomoldic porosity. Occasional light green clays were located in solution pipes or channels.

Minor quantities of siderite and marcasite were also observed and related to intraformational erosional surfaces. Clay mineralogy is not expected to differ greatly from that of rock types A and B.

Minor calcite recrystallization was observed in some of the vuggy porosity. It is thought to be due to hydrothermal replacement from percolating groundwaters. There is no evidence of massive recrystallization or dolomitization.

Apart from the fossil framework, very few faunal species were observed. Some fossil debris was incorporated in various algal mats, however these are thought to represent abraded, transported and redeposited fragments.

Primary biomoldic porosity is very high and not believed to have been affected by overburden compaction. Some secondary solution, vugular or fracture porosity was also observed, however this is quantitatively insignificant. Despite the high primary porosity, it is not thought that the degree of hydraulic communication is also necessarily high. Moreover, heavy bitumen saturation is believed to reduce in-situ permeability significantly. A measureable permeability anisotropy is not expected to exist.

3.3.6 Rock Type E - Uncemented Quartz Sand

Uncemented quartz sands are non-marine terrigenous deposits which are incompatible with the low energy shallow marine environment of the surrounding carbonates. They comprised less than 5% of the observed footage but represent significant solution features in proximity to the Devonian-Cretaceous unconformity.

Thickness is generally less than one metre and the sands are clean, uncemented, and medium to fine grained. They are mineralogically quartz-rich and display a very high degree of sorting. Individual particles are subangular to rounded, displaying both physical and chemical maturity. Traces of bedding may be observed, however a general lack of macrostructure characterizes the deposits. Incomplete bitumen staining adds to an apparent bedded appearance (Plate 3.12).

The sands are buff in colour with random black bitumen stains. Trace amounts of a silt or clay sized matrix were also observed. No carbonate minerals were detected.

There is no evidence of structural fracturing or weathering. Intergranular porosity is expectantly high. Permeability is also thought to be quantitatively significant and homogeneous.

The contacts of the sands with the surrounding carbonates was consistently abrupt and well defined. This character suggests post-depositional solution and subsequent infilling. Similar sand filled pipes and cavities were observed in field outcrop (Appendix D).

3.3.7 Rock Type F - Other Unconsolidated Sediments

Other unconsolidated sediments are similar to the quartz sands in that they represent early Cretaceous non-marine deposits. They commonly infill Devonian lows and are thought to be fluvial in origin.

The sediments are brown to grey, clayey silts and sands (Plate 3.13). They are poorly cemented which is thought to be a direct result of the relative youth of the sediments and a substantially reduced loading history. In the study core, the sediments were generally unstructured, however some bedding planes were observed. Occasional lignite particles were encountered which further supports a non-marine depositional environment. No other major macrostructures were observed, however there were rare instances of plastic deformation of the more clayey sediments. No algal growth or fauna inhabitation was observed.

The clay mineralogy of these sediments was considered in detail by Dusseault and Scafe (1979). Who dated them as early Middle Albian (Lower Cretaceous). One may thus relate their presence to the cessation of net erosion and the commencement of Cretaceous fluvial deposition. Current x-ray diffraction tests agreed with Dusseault and Scafe's findings which defined a kaolinitic-illitic dominance (see Section 4.3.3). Dusseault and Scafe

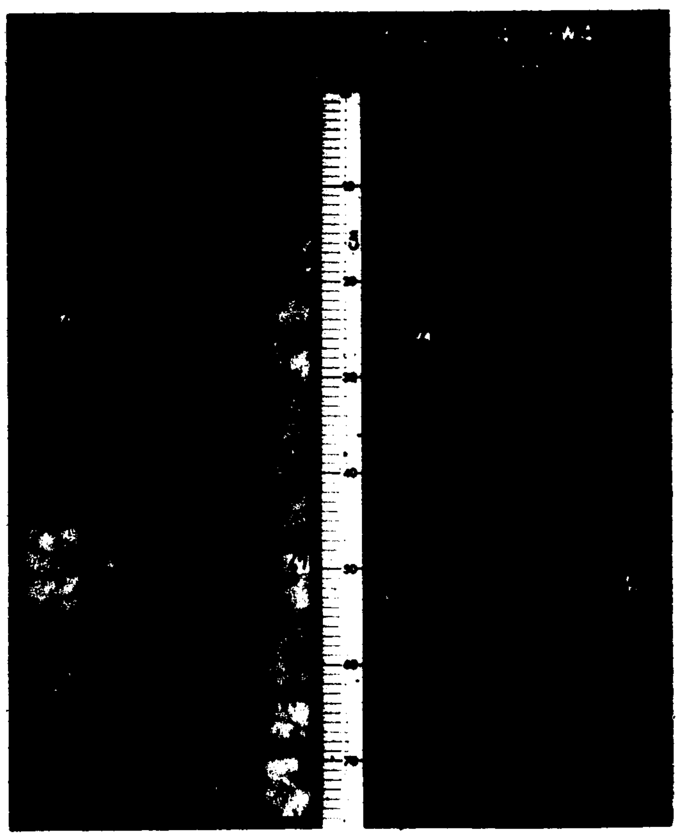


Plate 3.13: Rock Type F - Unconsolidated Cretaceous Alluvium (CH.118)

(1979) also reported significant mixed-layer clays and the presence of vermiculite, a distinct weathering or alteration product of phlogopite or biotite. The absence of chlorite and smectite is noted and of significance in reconstructing the geological origin of the deposits. Dusseault and Scafe (1979) further reported that the basal clays are non-calcareous, exhibit some primary bedding and contain minor amounts of lignite, siderite and pyrite. Observations made during the present study agree with these findings.

3.4 Depositional Environment

3.4.1 Generalized Carbonate Sedimentology

Carbonate sedimentation results from chemical or biochemical processes occurring in clear, warm, shallow marine environments. The process is autochthonous, suggesting that the sedimentary material is derived from within the depositional basin. No external terrigenous sources are considered.

The carbonate environment represents a sensitive chemical system which may be drastically affected by subtle changes in any one or a combination of the following parameters:

1. oxidation - reduction potential or Eh
2. hydrogen ion concentration or pH

3. climate
4. input and mixing of deep marine or terrestrial waters.
5. organic processes such as photosynthesis, bacterial decay and reproduction
6. tectonic processes such as subsidence, subduction and crustal movements.

Theoretically, the precipitation of calcium carbonate ($CaCO_3$) occurs upon a decrease in the concentration of dissolved carbon dioxide. The required decrease may be a result of temperature changes, evaporation, influx of saturated marine waters or organic processes. The chemical equilibria is given by:

$$Ca^{2+} + HCO_3^- \rightleftharpoons CaCO_3 + H^+$$

Other factors affecting carbonate production include the depth and turbidity of the seawater, agitation and solar radiation fluctuations.

Berner (1971) stated that seawater is not in equilibrium with calcium carbonate due to biological production and utilization of carbon dioxide. Ideally, there exists a "compensation depth" beyond which, calcium carbonate is dissolved as fast as it is produced. At depths shallower than the compensation depth, one expects supersaturated waters and continuous inorganic precipitation. In reality, the amount of direct carbonate precipitation is quantitatively insignificant relative to that which is produced organically. Berner (1971) concluded that widespread homogeneous precipitation of calcium carbonate is most unlikely.

The production of micrite or carbonate mud is also related to organic processes. Wilson (1975) identified four primary sources:

1. death and decay of benthonic organisms
2. detritus abraded from larger carbonate particles
3. accumulation of planktonic biota
4. direct seawater precipitation

In general, the presence of significant amounts of micrite discourages organic proliferation. Seawater turbidity reduces the amount of incoming solar radiation and "chokes" various benthonic invertebrates. Thus, most marine limestones are relatively pure carbonate. Alternatively, the Waterways Members are abnormally argillaceous, suggesting a very turbid or unstable environment. Wilson (1975) estimated current accumulation rates near Florida of 3 metres in 1000 years. The production of carbonate may start or stop rapidly and commonly occurs in a cyclic manner. Overall production may readily keep up with any amount of tectonic or eustatic sea level change (Wilson, 1975).

3.4.2 Depositional Model

Wilson's (1975) classical carbonate system is believed to represent a comprehensive and modern environmental model. It involves nine subenvironments of which only one or two are believed to be represented in the SANDALTA core. In general, Wilson's (1975) model involves a basin-slope-reef-platform system that predicts lower energy deposits seaward and higher energy, organic and wave-affected deposits shoreward. Figure 3.2 depicts the ideal series of subenvironments as presented by Wilson (1975).

Of the nine subenvironments listed by Wilson (1975), only the open marine and restricted marine platform facies are believed to be represented in the Waterways core. The open marine platform represents the zone immediately shoreward of the outer platform edge. Depth is generally less than 10 metres in straits, lagoons and bays. Salinity varies greatly due to moderate circulation. Argillaceous limestones, calcareous shales and undistrubed carbonate sands are typical deposits.

The restricted marine platform differs from the open facies in that virtually no circulation is envisaged. Static cut-off ponds and lagoons characterize the restricted platform and deposit fine grained carbonates, micrites and evaporites. The higher energy

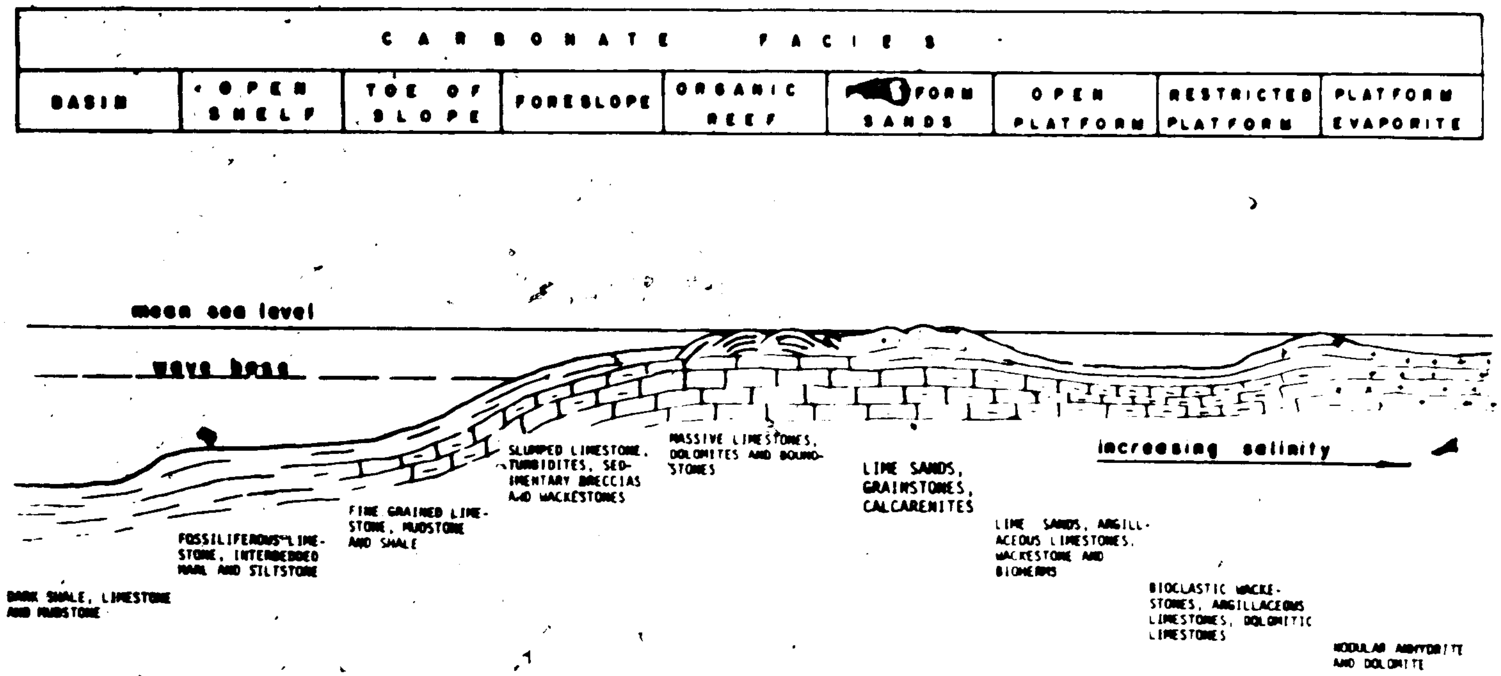


FIGURE 3.2: IDEALIZED MARINE CARBONATE SUBENVIRONMENTS (after Wilson, 1975)

tidal channel, tidal flat and beach deposits are also included in this facies.

In general, the platform subenvironment is considered to represent marine transgression. Although transgressive sequences are commonly erosional, the intrabasinal sediment source and high biogenetic content of the Waterways suggests a regressive environment is unlikely. Moveover, the observed Waterways sequence is believed to be progradational. That is, shallower water carbonates overlie the more seaward argillaceous lithologies. Prograding sequences are characterized by high rates of sedimentation and have high preservation potential. These factors are controlled by the change in ambient sea level which is in turn affected by tectonism, isostatic crustal changes, climate and sedimentary compaction. In particular, shallow marine environments are especially sensitive to climatic changes. This sensitivity promotes cyclicity in the depositonal process, a feature which is very prominent in the Waterways. More specifically, seasonal fluctuations in temperature, solar influx and winds are considered to exercise the greatest influence. The more restricted the environment, the greater the seasonal climatic influence. Such influence defines a high stress environment which is characterized by a low degree of diversity in organic species. Tectonic tilting, isostatic depression or rebound and changes in ocean volume are less likely sources of bedding cyclicity.

James (1979) further defined the shallow intertidal platform stating that it is devoid of active wave influences but still affected by tides and intermittent storms. He added that the lower intertidal zone is characteristically well burrowed and bioturbated with greater algal mat development than in the middle or upper intertidal zones (Figure 3.2).

3.4.3 Facies Interpretation

By definition (Gressly, 1838), the term "facies" applies to units of rock which are characterized by similar lithological and paleontological criteria. The present study is concerned only with lithofacies which are units of rock characterized by variations in lithologic aspect. Each lithofacies is directly related to the immediate marine environment, however factors such as climate or tectonics may also affect the final rock lithology.

Reineck and Singh (1980) described two basic approaches in reconstructing sedimentary environments; that of lateral or vertical facies. The technique employed in this study is the former. Although all rock types were identified in vertical core, it is apparent that the distribution of each lithology is primarily controlled by the lateral variation of depositional environment.

The scale of Wilson's (1975) depositional model is limited only by the confines of ancient depositional basins. Regional correlations suggest that the Waterways represents only one small component of the Western Canadian sedimentary basin. One should therefore not expect to view all nine subenvironments within an area such as SANDALTA. The scale of the Devonian basin in Western Canada is very large, extending across several provinces and southerly into the northwestern United States. Within this framework, it is apparent that the lithologies of the Waterways Formation correspond to the open or restricted lagoonal or intertidal flats of the shallow marine platform. This subenvironment may, in turn, be subdivided into three depositional zones recognized by the author. They are the shale, biohermal and carbonate zones, which are collectively responsible for the six lithologies described in Section 3.3. Each depositional zone and its corresponding lithofacies are presented diagrammatically in Figure 3.3. Again, each depositional zone defines a unique local environment within the widespread marine platform subenvironment.

The seaward shale zone represents deeper, quieter water than the biohermal or carbonate zones. Carbonate production is less significant than micritic input due to the abrasion of skeletal material and the settling of suspended load from the back reef lower intertidal zone.

Organism development is restricted due to high turbidity, however hardy brachiopod species may survive. A significant detrital fossil component may be present. The characteristic lithology is a well cemented, fissile calcareous shale. The shales are illitic and may contain iron sulphides such as marcasite. They are generally massive and undisturbed. There is little or no evidence of bioturbation. Consolidation is thought to occur uniformly leading to a homogeneous and well indurated rock texture. Occasional limestone interbeds may develop upon shallowing, however the sequence is predominantly argillaceous. This environment is not as sensitive to climatic changes as the restricted carbonate zone. The calcareous shales of rock type B are considered to be of the lower to middle intertidal platform shale facies.

Adjacent to the shale zone is the intertidal patch reef or <u>biohermal zone</u>. In Figure 3.3 this zone does not separate the shale and carbonate zones, however it does appear to do so at SANDALTA. Two distinct lithofacies are associated with the zone; the biohermal limestone of rock type D and the seaward intraclast breccia of rock type C.

The intertidal biohermal zone is characterized by shallow water organic buildups or patch reefs. These

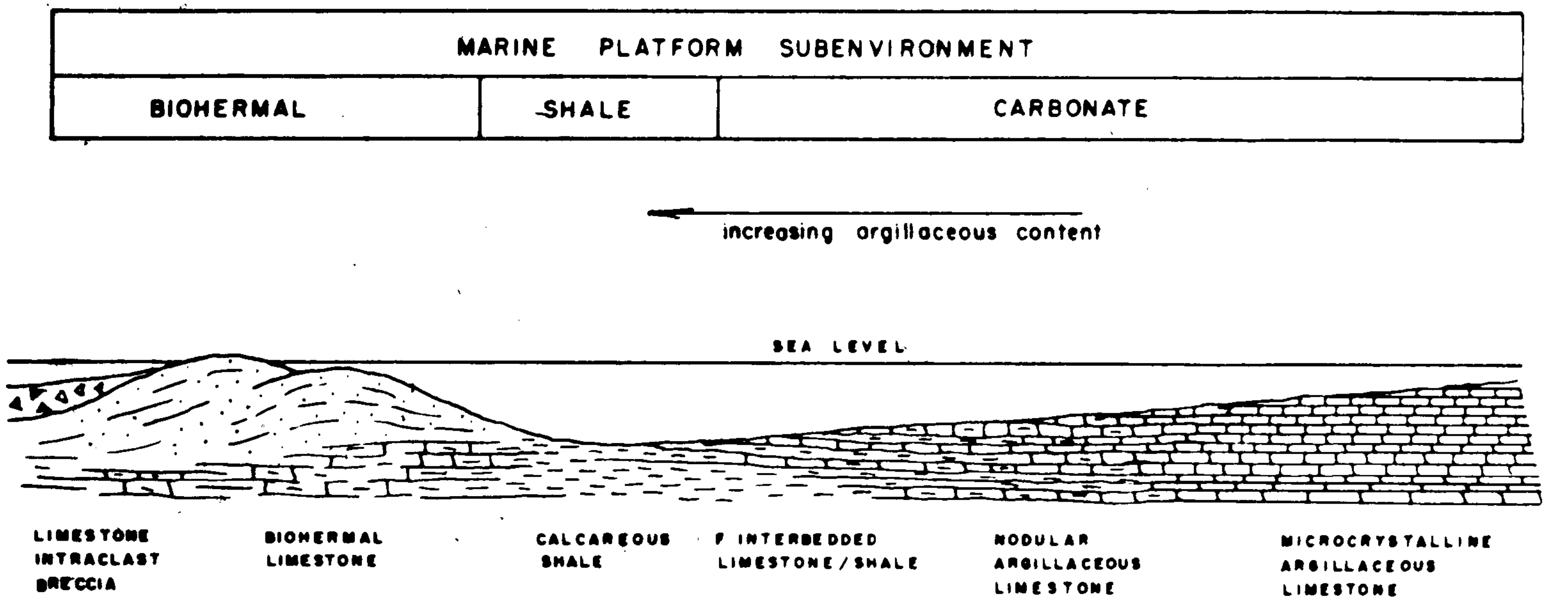


FIGURE 3 [illegible]ALIZED MARINE PLATFORM SUBENVIRONMENT AND LITHOFACIES buildups do not represent the coral reef barrier where very deep water and high energy wave activity is found. Instead, the bioherms are sporadically distributed and generally less than 2-3 metres in thickness. Lithologically, they are frame-supported algal structures with a heavy bitumen stain infilling the high biomoldic porosity. They are generally wave-resistant and easily identified on the basis of their well indurated, mounded biolithic texture. The bioherms were thought to be mildly wave-affected and subject to intermittent subaerial exposure. This influence is believed to be responsible for the development of the adjacent seaward facies, the intraclast breccia.

The intraclast breccias represent wave eroded biohermal or carbonate deposits which have fallen to the seaward toe of the bioherm. The resulting texture consists of angular intrabasinal carbonate clasts cemented in an argillaceous groundmass. Other sedimentary features are rare.

Shoreward of the biohermal and shale zones is the shallow carbonate zone. This zone is thought to be widespread but with restricted circulation and input. Indigenous carbonate production is the dominant sedimentary process, however a substantial micritic component may also result from the high benthonic population. Again, the argillaceous material is intrabasinal; a consequence of the abrasion and disintegration of green algae and calcareous skeletal material. Some direct precipitation of aragonitic muds is also expected as a by-product of local organic activity.

The depth of water in the platform carbonate zone is not considered to exceed 3 metres. No circulation is envisaged, however some wind-generated wave activity may be present. Shallow wave ripple marks may have developed near the shore during periods of non-deposition. Nodular or concretionary activity is also envisaged.

The shallow nature of the carbonate zone is primarily responsible for the extreme sensitivity of carbonate production to climate. This sensitivity is manifested in the finely interbedded lithologies that characterize the Waterways.

The development of intrabasinal hardgrounds is also thought to be due to changes in climate. Diastems or periods of non-production are initiated by temperature or solar fluctuations which result in the crystallization of the submarine floor. In section, these dense sparitic surfaces act as convenient timelines. Although they do not represent erosional features, intermittent periods of uplift resulting in subaerial exposure are also believed to have occurred. Low energy reworking and oxidation of surficial sediments is thought to have led to the development of the distinctive light green plastic clays which infill small intraformational solution pipes (see Section 4.3.3). Short-lived hiatuses are also supported by the existence of intraformational solution features which do not extend to the Devonian-Cretaceous unconformity.

Other features of the carbonate zone include a high benthonic population and occasional supratidal coquina deposits. The development of local algae mats or algal balls is also common. Bioturbation may be expected due to the high organism content, however this was not widely recognized in the Waterways.

Three lithofacies were identified within the carbonate zone. They are the massive to marbly crystalline limestone, nodular argillaceous limestone and finely interbedded limestone-shale facies. Each facies is gradational, changing laterally into one another. Furthermore, the exact conditions of their development are not drastically dissimilar. The primary factor distinguishing the three facies is depth of water. In general, deeper water displays reduced sensitivity to climatic effects. Thus, the deposits may reflect less variation in lithology, mineralogy or depositional structure.

In contrast, the shallower shoreward waters are very sensitive to seasonal effects. A textural cyclicity is thus imparted. Alternating carbonate-micrite production is a direct consequence of the changes in temperature, solar input and winds associated with a change in season. This cyclicity is poorly defined in the mottled or nodular facies but is well defined in the finely interbedded facies. The shallower shoreward waters are also expected to display a greater diversity in faunal content and sedimentary structure.

In summary, three distinct depositional zones have been defined within the marine platform subenvironment. Six lithofacies have been related to those zones and are distinguished on the basis of textural character. Depth of water and climate are considered to be the two factors exercising the greatest influence upon textural character. Each lithofacies is illustrated in Figure 3.3. All stratigraphic sections in Appendix B employ the preceding model.

3.5 Geophysical Measurements

3.5.1 General

The presence of dense, sparitic hardground surfaces was initially expected to provide well defined kicks in borehole neutron and density logs. Ideally such surfaces could be correlated in section. Unfortunately these surfaces were generally less than 10 cm thick and could not be readily identified on the oilfield geophysical tools employed at SANDALTA. This method of study was discontinued.

A second approach involved correlating rock mass lithology to bulk density, neutron density and gamma ray log responses. Geophysical cross plots were created which may be employed to distinguish gross borehole lithology and geotechnical suitability.

3.5.2 Bulk Density, Neutron Density and Gamma Ray Logs

A common suite of oilfield geophysical logs includes gamma ray, neutron density, bulk density and caliper logs.

Caliper logs provide a continuous mechanical record of the borehole sidewall conditions at the time of logging. It is useful in identifying unconsolidated or washed-out zones. The borehole integrity may often provide information about lithology, hydrogeology or structural geology.

Bulk density logs are achieved by employing a radioactive source in the measuring instrument. The separation of a transmitter and receiver will determine the depth of penetration of the gamma ray radiation. Theoretically, the amount of radiation recorded at the receiver is directly proportional to the electron density of the rock mass. Electron density may then be related to the true bulk density which itself is dependent upon mineralogy, porosity and formation fluid.

Neutron density logs also employ a radioactive source, however in this instance, high energy neutrons are emitted. The collision of the neutrons with hydrogen ions in the formation causes a significant loss of energy. A receiver or counter then detects what proportion of the emitted neutrons were not affected by hydrogen ion collisions. The resulting response provides a measure of the concentration of hydrogen ions in the rock mass. Since hydrogen occurs in both water and hydrocarbons, the neutron log is used primarily in determining liquid-filled porosity.

Gamma ray logs are a third nuclear log providing information on the natural radioactivity of the rock mass. In sedimentary rocks, the common radioactive elements are concentrated in the various clay minerals. Thus, gamma ray responses are normally used to determine shale content. High energy electromagnetic waves emitted by the source experience Compton scattering collisions with the formation atoms. After losing a significant amount of energy, gamma rays are adsorbed by formation atoms by the photoelectric effect. The subsequent ejection of electrons from the host material is measured by the geophysical receiver. These emissions are quantitatively related to the amount of radioactive potassium, uranium and thorium isotopes in the formation. Since the concentration of uranium and thorium isotopes in sedimentary rocks is commonly insignificant, the measure of emitted radiation is directly related to the potassium content in the clay minerals. This in turn is interpreted as a bulk representation of the overall shale content of the formation.

3.5.3 Facies Cross Plots

Six geophysical cross plots have been prepared illustrating four distinct carbonate lithologies. Three types of cross plots have been employed, including the following:

1. gamma ray vs. bulk density
   (Figures 3.4, 3.5)
2. gamma ray vs. neutron-neutron
   (Figures 3.6, 3.7)
3. bulk density vs. neutron-neutron
   (Figures 3.8, 3.9)

Each cross-plot was established by matching observed borehole lithologies with the corresponding geophysical response. An inventory of study core sections was completed and all data plotted by rock type.

Theoretically, geophysical tools should respond only to changes in the physical properties of the formation. In practice, each instrument is also sensitive to drilling fluid and borehole conditions. The author has attempted to minimize these influences by plotting average geophysical response. Minor fluctuations have been ignored.

Figures 3.4-3.9 represent cross plots completed for the SANDALTA lease. The following conclusions may be drawn:

1. Gross lithologic character may be readily distinguished on the basis of geophysical response. Subtle facies differences are less well defined. Differentiation of individual limestone facies could not be established without overlap.
2. Gamma-ray-neutron-neutron and gamma ray-bulk density plots were found to be the most useful in distinguishing lithofacies. High gamma ray responses coupled with low bulk or neutron densities were found to be characteristic of the more argillaceous lithologies. Alternatively, high neutron density and low gamma ray responses were characteristic of the porous biohermal limestones and less argillaceous, finely interbedded facies. Massive crystalline

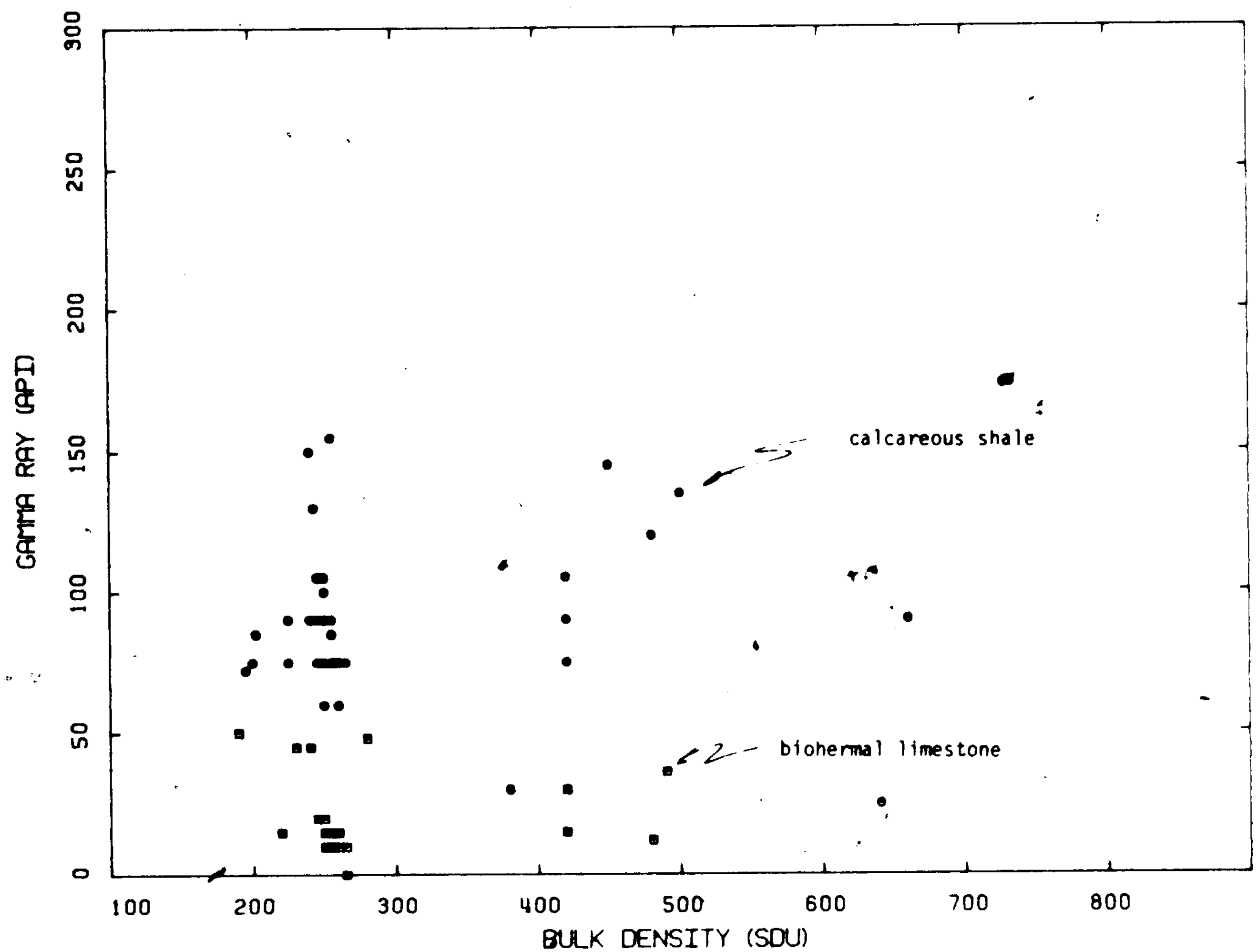


FIGURE 3.4: GAMMA RAY-BULK DENSITY GEOPHYSICAL CROSS PLOT

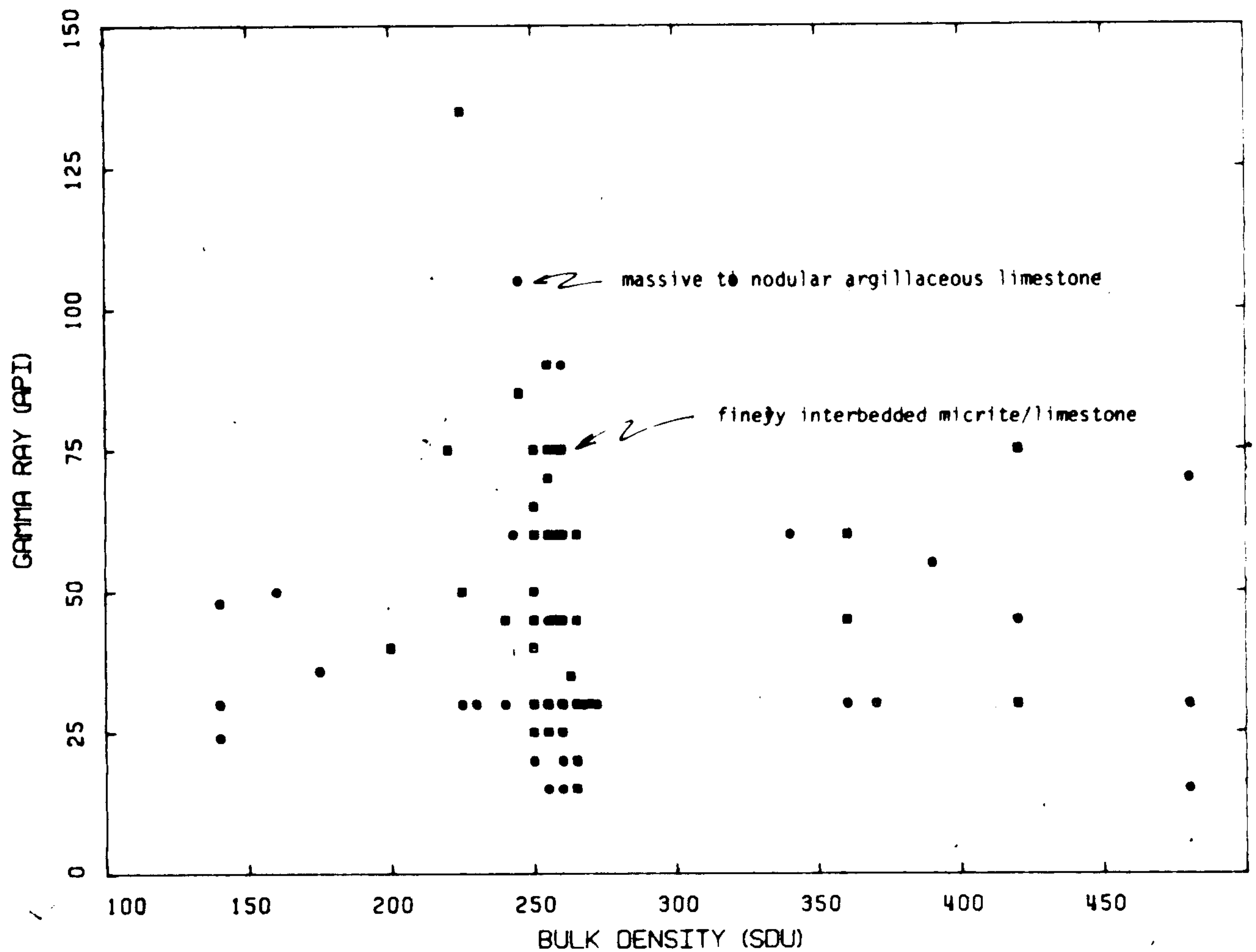


FIGURE 3.5: GAMMA RAY-BULK DENSITY GEOPHYSICAL CROSS PLOT

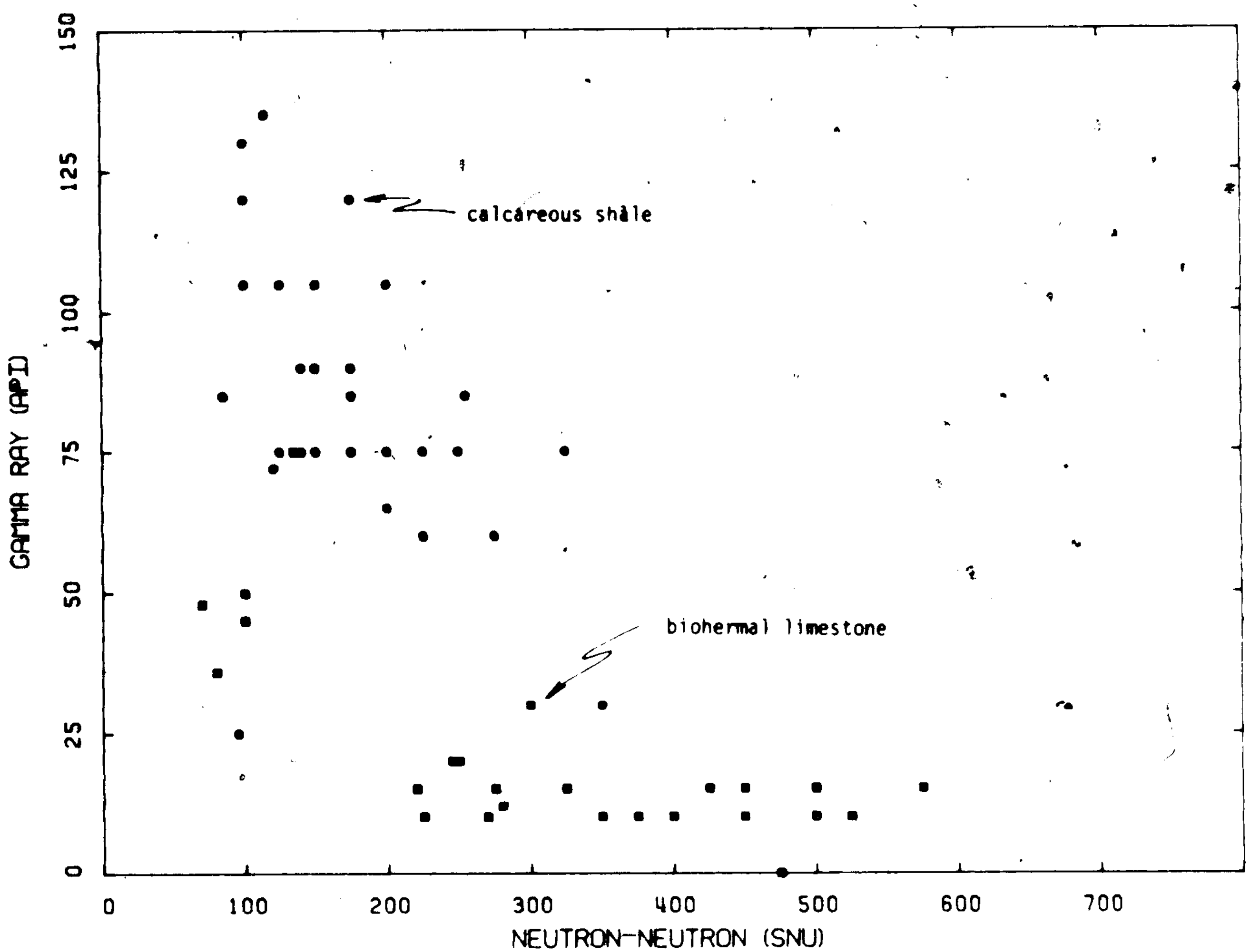


FIGURE 3.6: GAMMA RAY-NEUTRON GEOPHYSICAL CROSS PLOT

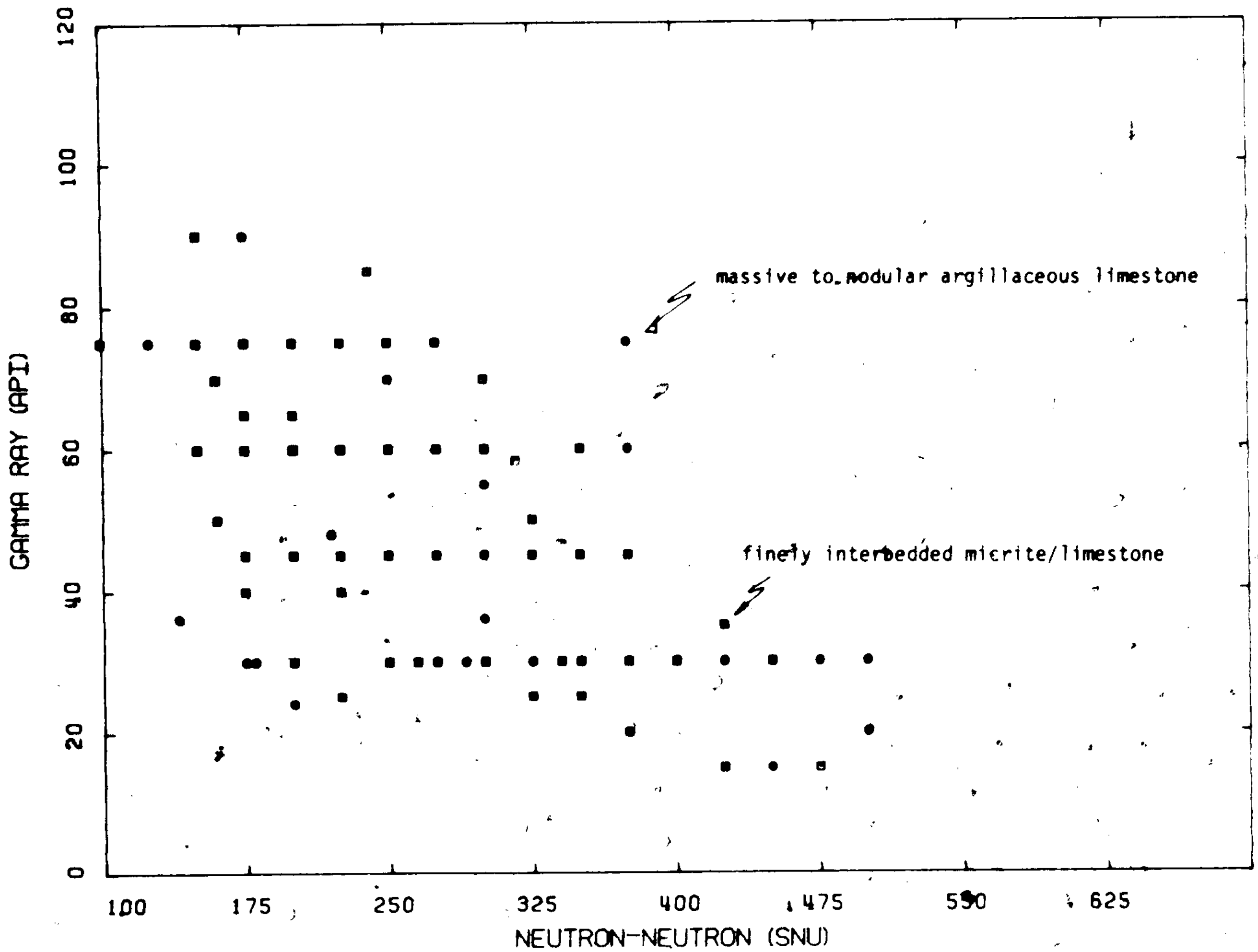


FIGURE 3.7: GAMMA RAY-NEUTRON GEOPHYSICAL CROSS PLOT

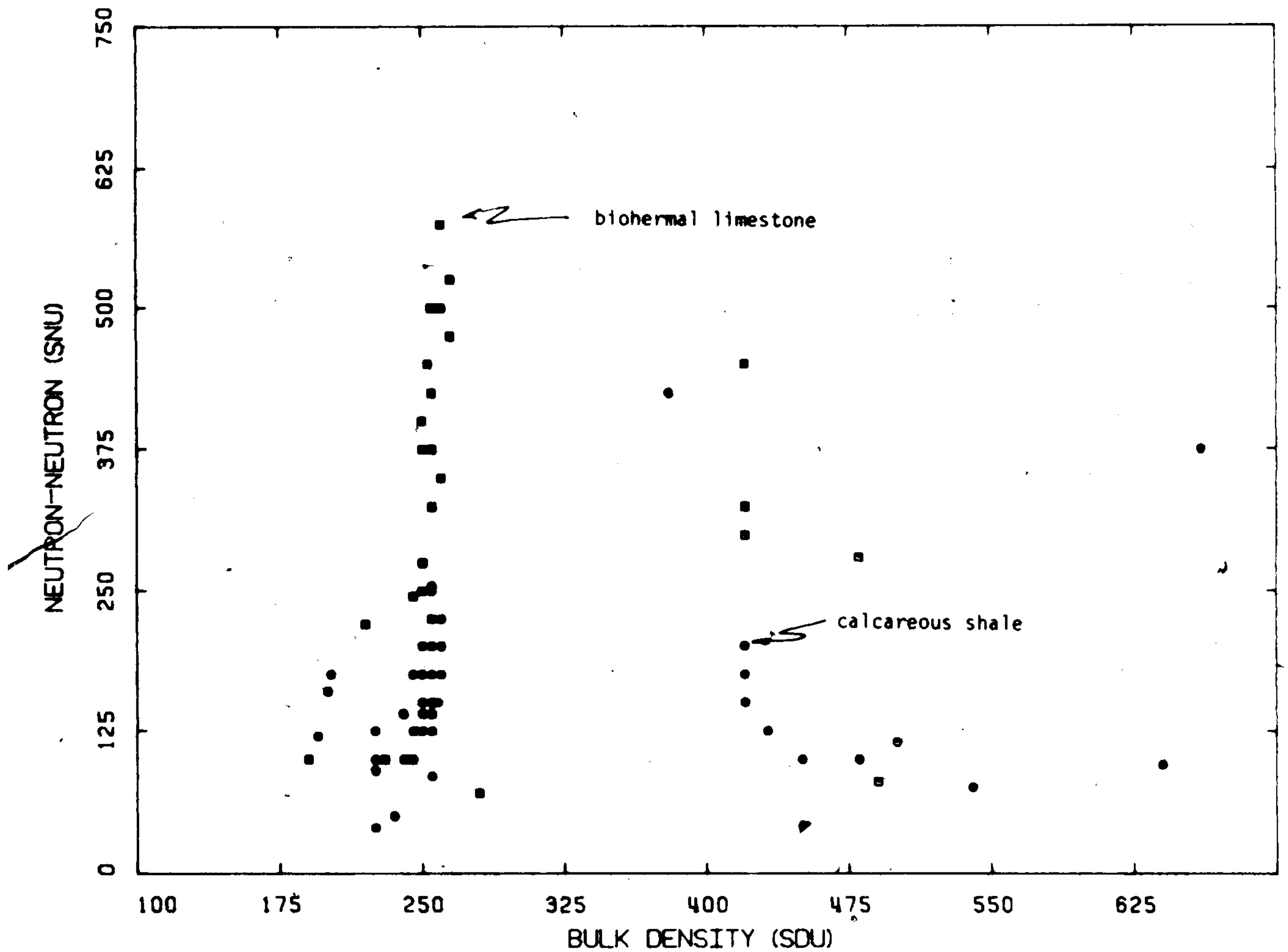


FIGURE 3.8: NEUTRON-BULK DENSITY GEOPHYSICAL CROSS PLOT

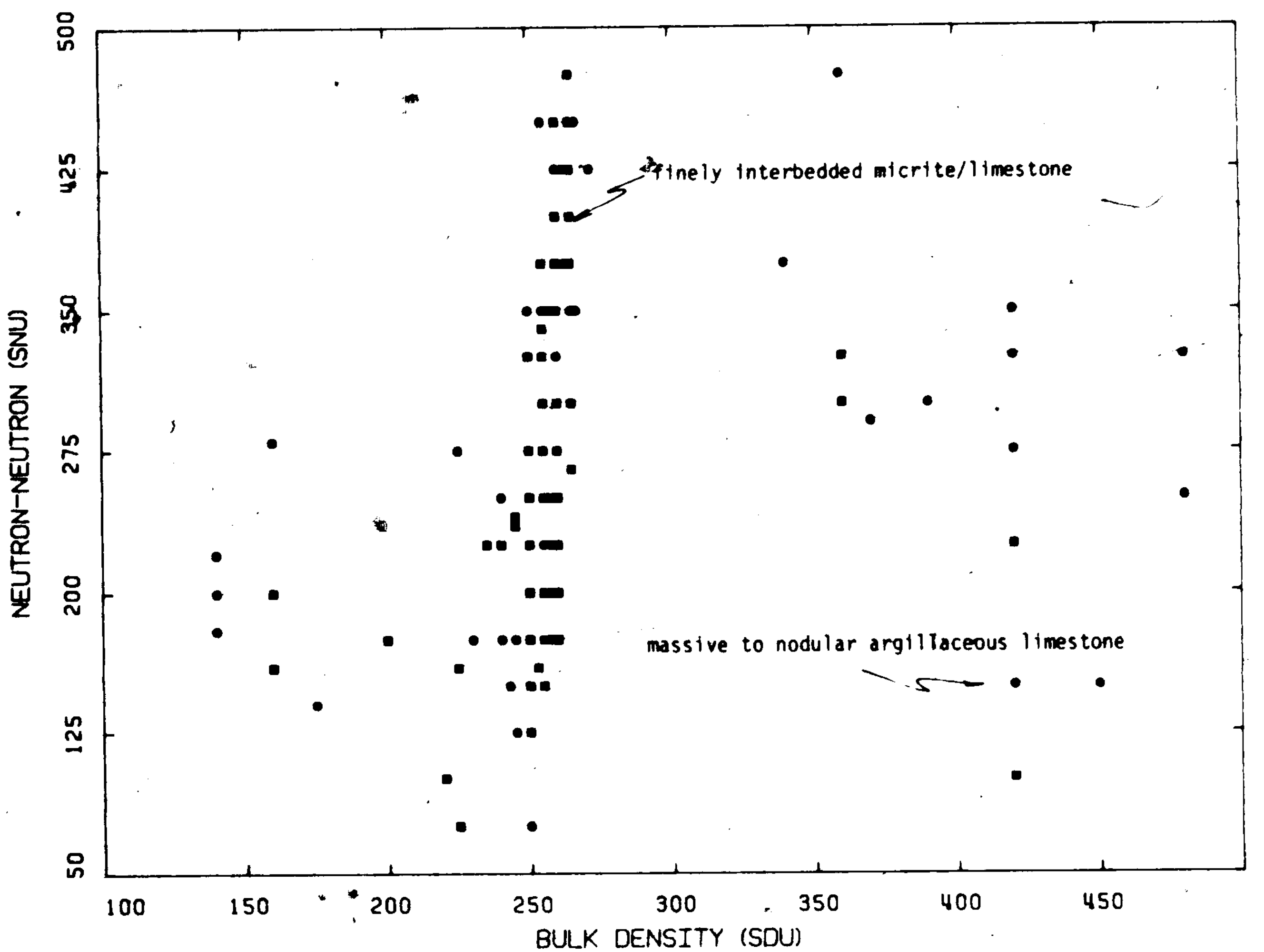


FIGURE 3.9: NEUTRON-BULK DENSITY GEOPHYSICAL CROSS PLOT

limestones displayed both low gamma ray and neutron-bulk density responses.

3. General geotechnical information on rock mass quality may be acquired from geophysical cross plots. In particular, undesirable argillaceous rocks may be indentified on gamma ray plots and porous, permeable units may be distinguished by the neutron density response. Overall rock mass densities may be assessed on bulk density plots and may provide preliminary information on the degree of consolidation, compaction, or cementation of a particular lithologic unit. Finally, liquid-filled aquifers may be identified and the nature of the aquifer fluid may be established.

3.6 Structural Geology

3.6.1 Small Scale Primary Structure

The development of syndepositional textures and structures dominates the lithology of the Moberly and Christina members. Features such as laminations, ripple marks, carbonate nodules or concretions, algal mats, fossil beds and intraformational hardground surfaces are common.

Well defined bedding planes are most pronounced in the finely interbedded limestone-shale facies of rock type A. Most bedding occurs on a centimetre scale and is generally planar to wavy with a subtle subhorizontal dip (Plate 3.7). Interbedding is highly regular and thought to be due to the cyclic influence of seasonal climatic variations. Millimetre scale laminations were also observed. They were most prominent in the calcareous shales of rock type B.

Both strength and permeability anisotropies may be affected by bedding. Bulk deformation moduli may also be affected.

Syndepositional ripple marks are another primary structural feature observed in outcrop (Appendix D). They are thought to have formed in the wind-influenced shoreward zone and were most commonly observed in the argillaceous or interbedded facies of rock type A. They are not expected to be of any engineering significance.

Concretionary features are less significant primary structures, but may affect localized engineering behaviour as heterogeneous, stiff inclusions. Concretionary nodules up to 20 cm in diameter were observed in outcrop (Appendix D). They are thought to have formed syndepositionally and may have been exaggerated by post depositional differential compaction. The nodules are tabular or elongated and aligned perpendicular to the expected paleocurrent direction.

Algal mats and balls were not observed in the core but were revealed in weathered outcrops along the MacKay and Muskeg Rivers (Appendix D). Finely laminated wavy mats signify a temporary stoppage in carbonate production and establishment of a stable marine substrate. Mats were not found to exceed 10 cm in thickness and are thought to have formed in the shallow shoreward environment. They are of little engineering significance.

The development of intraformational hardground surfaces was previously discussed in Section 3.3. These surfaces were found to be largely indistinguishable on geophysical logs and of limited engineering significance, however they do represent dense, impermeable horizons.

The primary clastic texture of the limestone intraclast breccias was distinguished from the post-depositional collapse breccias in Section 3.3. The intraclast breccia is composed of local limestone clasts in a dark brown, argillaceous matrix. The clasts are slightly rounded and display a random, disoriented character. This texture suggests a moderate degree of transportation and reworking. The breccia may also be bitumen stained. In contrast, in-place collapse breccias are composed of angular, massive or interbedded limestone clasts with little or no argillaceous matrix. In some instances, collapse has involved only a few centimetres of displacement. Former bedding planes may be occasionally established. These breccias are interpreted to be post-depositional, solution collapse structures, distinct from the primary depositional texture of the biohermal intraclast breccias.

The non-homogeneous texture of both brecciated lithologies is expected to influence non-homogeneous engineering behaviour. Moreover, the disturbed character is thought to affect reduced compressive and tensile strengths relative to the undisturbed carbonates. Both breccias may also display significant compressibility and lower deformation moduli than the more massive limestone lithologies. In general, these units are thought to represent very poor geotechnical materials.

Finally, the development of pinch and swell structures is considered. These were observed throughout the study core on a centimetre scale (Plate 3.14) and on a decimetre scale in field outcrop (Appendix D). Boudinage refers to angular or barrel-shaped bodies of brittle rock, sandwiched between adjacent layers of deformable or plastic sediments. It is generally accepted that boudinage forms upon compression normal to the bedding plane (Ramberg, 1955; Ramsey, 1967). Boundary contact forces are produced causing the brittle unit to fracture in tension (Figure 3.10).

Boudinage is well preserved in the study core and river outcrops of the Moberly member. Cyclic deposition

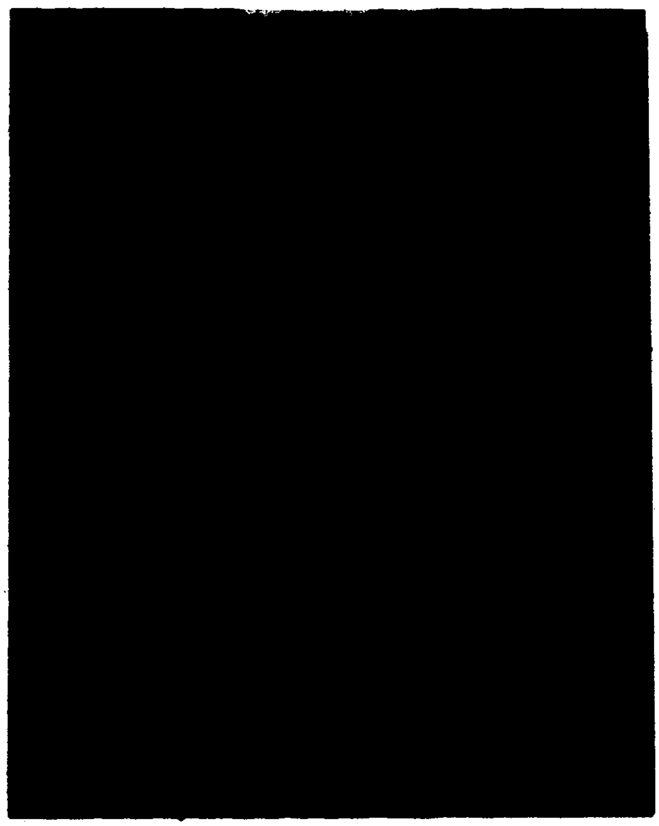


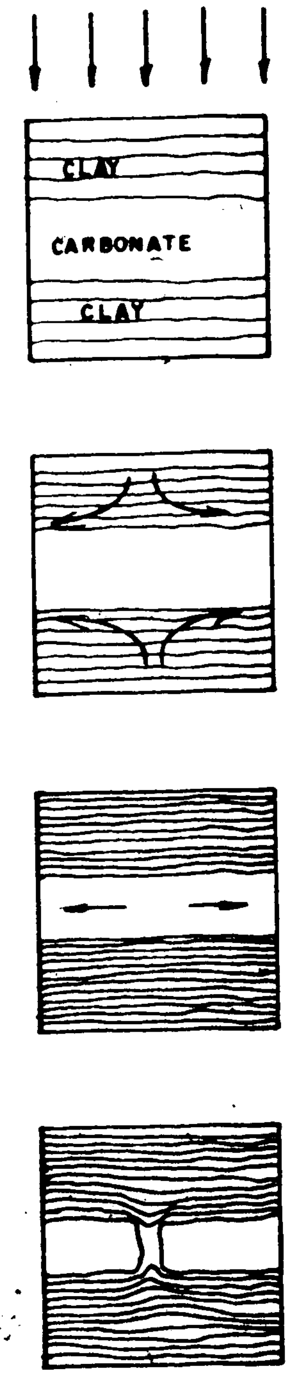
Plate 3.14: Boudinage (CH.137)

of micrite and carbonate has led to regular interbedding. Subsequent burial is considered to have compressed the plastic sediment, thereby effecting consolidation of the clay layers and lithification of the interbedded carbonates. Further overburden compression is thought to have developed boundary frictional stresses leading to tensile fracturing of the stiff carbonate layers and plastic deformation of the clay interbeds. Numerous boudins are created without erosional or tectonic influence.

The presence of boudinage implies a subvertical major principal stress prior to lithification. Once lithified however, the rock mass is perceived to have the structural rigidity to undergo loading resulting in an elastic response. Brittle fracturing would then be the anticipated failure mode.

The engineering significance of boudinage lies in the creation of secondary fracture porosity and accompanying vertical permeability. Rock mass shear strength and deformability may also be reduced.

In summary, small scale primary structures are abundant and include laminations, ripple marks, concretions, algal mats and balls and intraformational hardground surfaces. Both syndepositional and post depositional breccias have been identified and small scale boudinage was commonly observed.



- HYDROSTATIC LOADING ON THE MARINE FLOOR
- CONSOLIDATION OF CLAY LAYERS, CEMENTATION OF THE CARBONATE

- CONTACT (DRAG) FORCES CREATED AT CLAY/ CARBONATE BOUNDARY
- MILD TENSION CREATED IN STIFF CARBONATE

- EVENTUAL TENSILE FAILURE OF CARBONATE LAYER

- PLASTIC DEFORMATION OF CLAY LAYERS ABOUT BOUDIN
- SECONDARY POROSITY AND PERMEABILITY CREATED BETWEEN BOUDINS

FIGURE 3.10: BOUDINAGE MECHANISM

3.6.2 Small Scale Secondary Structure

The development of small scale secondary structure is limited in the Waterways. The majority of secondary features are regional in scale, however mild diagenesis, weathering and bitumen staining shall be presently considered.

Low grade hydrothermal alteration or diagenesis are short-lived processes thought to have affected Waterways sediments immediately following deposition. The presence of the iron minerals siderite and marcasite support this hypothesis.

Berner (1971) suggested that iron carbonates such as siderite and iron sulphides such as marcasite form only during diagenesis in sedimentary rocks. Their chemical stability is a function of the oxidation-reduction potential of the host environment and the amount of free iron and sulphur available. Both minerals are unstable in high Eh or aerobic environments. Thus, although high sulphur, iron and carbon dioxide concentrations characterize low Eh environments, these conditions are not expected in the shallow marine environment.

Low Eh values may result from anaerobic bacterial decomposition or as a result of the exposure of fresh sediments to non-marine anaerobic groundwaters. For concretionary siderite to be stable, the concentration of dissolved ferrous iron must be greater than that of calcium. The remains of various benthonic fauna and bacterial sulfate reduction are two processes thought to create the necessary iron-sulphur concentrations. Neither mineral will form or remain stable in an acidic, aerobic environment. Thus, the development of siderite and marcasite is viewed as an indication of low grade, early post-depositional diagenetic, replacement or concretionary mechanisms within the ancient submarine floor. Later hydrothermal replacements are also expected, however there is no evidence to support the widespread development of metasomatism or dolomitization. Minor calcite recrystallization is attributed to local groundwater effects.

Although these diagenetic processes are of little engineering significance, the presence of unstable marcasite is noted. The oxidation of marcasite near joint walls and intraformational unconformities may result in significant volume changes. As a result, adjacent structures may experience significant point loading. The temperature increase associated with in-situ recovery methods is considered to catalyze the oxidation reaction.

Bitumen staining is another secondary feature observed throughout core samples and river exposures (Plate 3.4). Two potential bitumen sources are defined. Firstly, shell beds observed in outcrop (see Appendix D) displayed a distinct heavy, black bituminous stain. This bitumen is considered to have formed in-place as no see page channels were observed and the stain is limited to the porous organic lenses. It is believed to be the result of decomposition of faunal remains contained within various coquina deposits. The bitumen stain that characterizes the biohermal facies is also believed to be local in origin, however the majority of these units do exhibit hydraulic communication with the overlying Cretaceous sediments.

The second source of bitumen is believed to be the overlying Cretaceous McMurray Formation. Structural communication by subvertical joints is thought to have permitted gravitational infiltration of lighter hydrocarbons. Although some authors (Link, 1951) have proposed a Paleozoic source for the bitumen, the present author believes that Waterways infiltration occurred concurrently with infiltration into the McMurray Formation. This is supported by the occurrence of bitumen in post-depositional fractures and an apparent loss of stain with depth. Furthermore, there is no evidence of a major Upper Devonian source rock. These features suggest that bitumen infiltration into the Waterways was gravitational. Additional support is found in the nature of solution infillings observed along the MacKay River. The implications of bitumen infiltration are discussed in Section 4.3.2.

The time of bitumen infiltration is believed to have been Late Cretaceous. It would therefore have been preceded by Paleozoic jointing and Mesozoic erosional and depositional occurrences. Mossop (1980) indicated that the Lower Cretaceous Mannville Formation was the likely source of McMurrary hydrocarbon.

Weathering profiles may also be considered a secondary feature. In general, weathered Devonian surfaces were discoloured, but essentially undisturbed. Some loss of texture was observed at the Devonian-Cretaceous unconformity, however widespread residual soil development was not encountered. The author subsequently distinguishes between non-marine basal McMurray alluvium and weathered Paleozoic materials. Basal McMurray deposits are discussed in detail in Section 4.2.2.

It is proposed that light green, plastic, non-calcareous clays are the sole weathering product of the argillaceous Waterways limestones. Mineralogically, they correspond to sources within the Waterways (see Section 4.3.3) and do not appear to be related to Cretaceous deposits overlying the unconformity. More commonly, these clays infill solution pipes in the karst horizon and occupy topographic lows. They do not appear in significant thicknesses in any core sections and commonly form a thin (10-30 cm) mantle atop intact limestone. This suggests that weathering processes may have been relatively short-lived. Moreover, these clays are thought to represent reworked surficial slimes as opposed to in-place residual soils. An idealized weathering profile is presented in Figure 3.11. Plate 3.16 depicts a typical weathering feature.

The engineering significance of the plastic clays is potentially unique. Although they may not be spatially widespread, they are believed to characterize the Devonian-Cretaceous unconformity which represents a major engineering horizon. Due to their high plasticity and expected low shear strength, these materials are considered to be geotechnically undesirable. They may accentuate trafficability, bearing capacity or highwall stability concerns. , These problems are discussed in Section 5.3.

Another secondary weathering feature is that of weathered rims surrounding joint fractures and solution cavities. Although joint walls may be slightly discoloured due to oxidation, a significant loss of rock mass strength is not expected. Minor softening may be experienced in extreme cases. Sporadic calcite recrystallization was observed, however widespread joint recrystallization is not envisaged.

In summary, mild hydrothermal alteration, bitumen staining and weathering have been identified. Regional recrystallization was not observed. Weathering features are treated in Section 4.3.

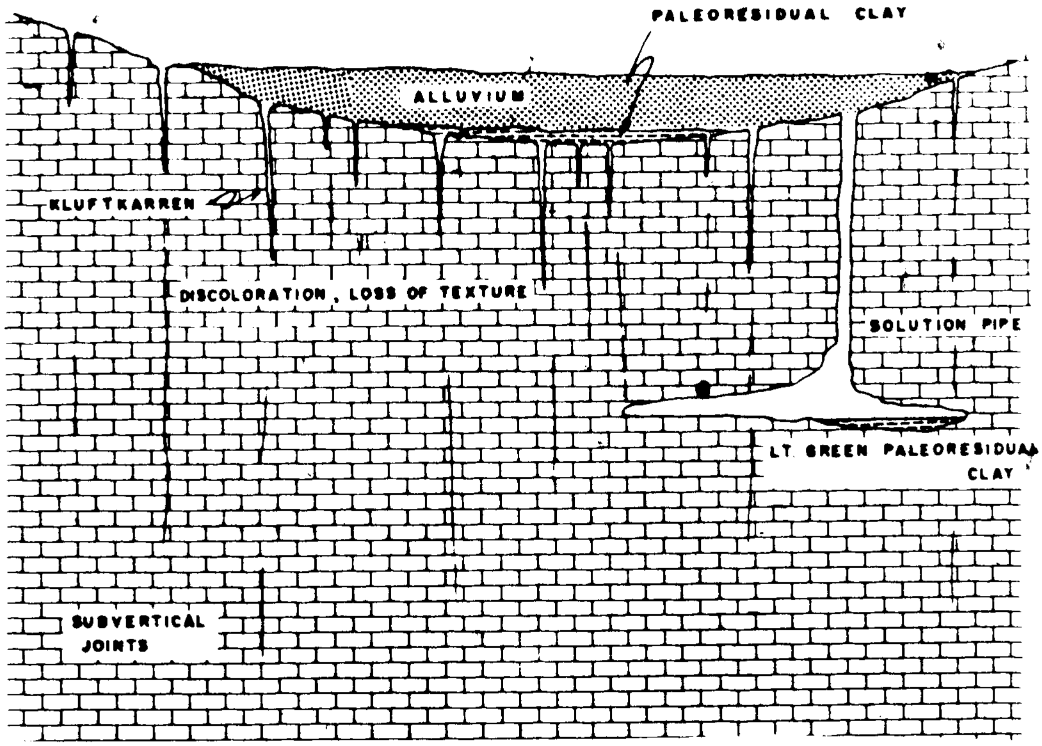


FIGURE 3.11: IDEALIZED WEATHERING AND SURFACE SOLUTION FEATURES

3.6.3 Large Scale Primary Structure

Large scale primary structures are limited to the distribution of the various lithofacies and the development of numerous intraformational hiatuses. The most significant structural features are post-depositional in origin.

The distribution of depositional lithofacies was discussed in Section 3.4 where a marine platform model was developed. The structural significance of the distribution of each facies lies in their individual propensities to compact differentially. The carbonate facies lithify faster than the argillaceous facies and would subsequently experience much less compaction settlement. Although differential compaction is thought to have emphasized relief upon former stratigraphic surfaces, it is not considered to have been a predominant structural influence. Of greater significance is the presence of intraformational unconformities.

Two distinct types of intraformational hiatuses were observed throughout the core study. Firstly, periods of non-deposition or diastems are thought to have developed dense, sparitic hardground surfaces. These surfaces have been previously discussed and may be employed as stratigraphic time lines in facies correlations. They do not represent erosional hiatuses and are described at length by Stoakes (1980). Their engineering significance is limited to the establishment of occasional impermeable, brittle horizons. Alternatively, two major intraformational erosional surfaces were identified in the SANDALTA section. Several minor erosional surfaces were also identified, however their correlative value is limited due to restricted regional extent.

Intraformational erosional surfaces were identified on the basis of their small scale solution features and well defined weathering profile. Light green plastic clays characterized the contact and oxidation staining was often apparent. A subtle loss of texture may have been observed and sparitic surfaces with pyritic rims or nodules were occasionally identified (Plate 3.17). Rudaceous deposits such as sands and gravels were not observed, which suggests a high energy erosional environment did not exist. Rather, the presence of overlying shales and carbonates indicates that a period of low energy subaerial exposure was followed by continued carbonate production. A significant change in depositional environment is not envisaged. The three major erosional surfaces include the following:

1. Devonian-Cretaceous unconformity

2. Biohermal unconformity - located at the immediate base of the biohermal lithofacies

between elevations 240 and 270 masl.

3. Sub-biohermal unconformity - located 3-8 metres below the immediate base of the biohermal lithofacies between elevations 230 and 260 masl.

Additional minor unconformities were identified immediately above and below the intraclast breccia facies (see Appendix B), however these are thought to correspond to intermittent periods of substrate exposure common to the facies subenvironment. They were not found to be laterally continuous and may not represent periods of regional exposure.

In summary, large scale primary features are limited to differential compaction and intraformational unconformities. Differential compaction has not been studied, however two types of intraformational hiatuses have been recognized. Diastems are periods of non-deposition resulting in hardground development whereas unconformities represent periods of uplift and subaerial exposure resulting in solution and surface weathering.

3.6.4 Large Scale Secondary Structure

Large scale secondary structures dominate the Waterways geology and include features related to subsidence, uplift, faulting, collapse and erosion. Many of these features are considered in detail in Chapter 4, however they are introduced and described presently. Structural events are considered in chronological order.

Following deposition and lithification of the interstratified carbonate and shale facies, the first structural event affecting the Waterways was likely that of regional subsidence. Prairie Evaporite solution is believed to have been an early consequence of deep hydraulic activity which in turn led to the development of collapse pipes and overall regional subsidence. This subsidence is considered to have formed the rolling basin structures observed in local Waterways outcrops. These flexures have amplitudes of 20-30 metres and wavelengths of several hundred metres (Norris 1973). Alternatively, Hume (1947) suggested the domes and basins were due to volume changes accompanying an anhydrite-gypsum transformation in the Prairie Evaporite. Regardless which of these mechanisms is responsible, flexures in the Waterways should not be considered to represent regional compressional folding. The flexures appear to be without a dominant regional trend and do not display compressional characteristics. Subsidence is considered to have been the predominant formational mechanism.

Concurrent with the creation of flexural basins was the brittle fracturing of beds at the perimeter of the basins. Outcrops along the MacKay and Muskeg Rivers (see Appendix D) display breaking features which are not considered to be due to regional compression. Bedding offsets could not be established and no shear characteristics were observed. These features are thought to represent local overstressing due to subsidence and are not related to regional tectonic faulting. Regional subsidence due to evaporite removal is considered to have continued throughout late Paleozoic and Mesozoic time. Solution may presently be occurring, however Prairie Evaporite removal at SANDALTA is believed to be complete (see Section 4.1.3).

Another early occurrence related to Prairie Evaporite solution was that of deep-seated collapse pipes. The initial stages of solution are considered to have occurred preferentially, thus creating numerous voids or caverns in the Prairie Evaporite and affecting a loss of support for overburden units. Local overstressing may have resulted in the formation of steep-walled collapse pipes which originate in the Prairie Evaporite and translate upward (see Section 4.1.3). The resultant rock structures observed in the Upper Devonian include slumped and brecciated examples of previously undisturbed sediments. These structures are post-depositional and typically appear as on plate 3.10. In this instance, previous bedding planes may be established and an overall gravitational collapse character is evident. There is no evidence of shearing or syndepositional slumping. Reworking and transportation are not evident. In Section

4.1.3, the observed collapse structures are distinguished from karst dolines which develop from the surface and may subsequently become infilled with unsorted detritus.

Regional jointing is another structural occurrence, believed however to be related to periods of uplift, not subsidence. Joints are vertically discontinuous and display no measurable lateral or vertical displacements. The joint faces are rough and fresh and display no slickensides, striae or stylolites. Spacings vary according to the stiffness and thickness of the particular lithology. All of these characteristics suggest that jointing in the Waterways was due to tensile stressing upon uplift. Compression is not suggested because inclined shear surfaces would be the expected mode of deformation. These features discount Cordilleran orogenic compression as suggested by Babcock (1975).

Periods of regional uplift are also considered to have occurred intraformationally. This is supported by the occurrence of intra-Devonian karst and weathered horizons. Karst on intraformational unconformities is poorly developed relative to the Devonian-Cretaceous surface. The unconformities are mildly undulating and may have been influenced by pre-existing topography or deep solution subsidence.

Uplift resulting in joint formation and intraformational erosion also induced significant secondary permeability. Despite dominant subhorizontal bedding, the development of subvertical joints, boudinage and solution and collapse pipes has likely contributed to a significant vertical hydraulic conductivity. Moreover, this is likely to have affected a significant permeability anisotropy throughout the Waterways. The stress dependence and implications of formation permeability are discussed in Section 5.4.2.

The establishment of secondary permeability is considered to have had an accelerative effect upon formation karstification. Structurally controlled solution pipes are known as kluftkarren (see Section 4.1.2) and are believed to characterize the Devonian-Cretaceous karst. Intraformational karsts are not considered to be structurally controlled. Typical solution pipes were less than 10 cm in diameter and possessed smooth walls with light green clay infillings. Larger pipes (up to 30 cm) and subhorizontal cavities were observed in the field (see Appendix D) and were commonly infilled with bituminous sands or brecciated limestone fragments. All kluftkarren pipes and cavities were widely confined to a apparent "active zone" within 1-2 metres of the various unconformities. These features are believed to have developed at the time of exposure and were subsequently terminated upon infilling with residual clays. The development of large (>3m) subsurface caverns is not generally supported by core features, however one section (CH.150) did illustrate approximately 10 metres of non-marine alluvium at depth.

Faulting within the Devonian is a phenomenon discussed by several authors as reviewed in Section 2.2. The present study provided no new evidence to support regional faulting and suggests structural continuity exists across SANDALTA. Normal faulting due to Prairie Evaporite removal is envisaged however cannot be supported by direct core evidence. No obvious stratigraphic offsets were detected and no examples of sheared surfaces were observed in the core. This does not preclude regional faulting but does suggest the SANDALTA locale is structurally intact. A detailed discussion of potential stress fields is found in Section 5.4.2.

The most recent structural events may be considered to be unloading due to erosion of upper Devonian sediments and reloading upon Cretaceous deposition. Mild isostatic rebound is likely to have occurred upon unloading, however no accompanying strains were distinguished. Early Cretaceous drainage carved deep fluvial channels which were subsequently infilled with uncemented detritus. These features are discussed in Section 4.2.1.

In summary, several episodes of uplift, karstification and subsidence are considered to have affected large scale structures within the Waterways. Prairie Evaporite solution is believed to have caused vertical collapse pipes and overall regional subsidence.

This may have been accompanied by steep angle brittle faulting, however there is no current evidence to support this mechanism.

There is no compressional folding in the Waterways, however evaporite removal has created local warping and basin structures. Jointing is common and a result of tensile overstressing upon uplift. Karst features are concentrated about intraformational unconformities and are largely joint controlled. Significant vertical permeability is created by joints and pipes and may be several orders of magnitude greater than horizontal.

3.6.5 Structural and Stratigraphic Correlations

The following general conclusions were drawn from a review of vertical cross sections reproduced in Appendix B.

1. The Moberly and Christina members display a high degree of lateral variation in lithologic character. Vertical textural variability is less pronounced. Lateral facies continuity was established across SANDALTA and may be predicted by employing the marine carbonate model discussed in Section 3.4. Such continuity suggests the immediate Waterways members are part of a

widespread carbonate system that affected the entire Western Canadian sedimentary basin. Local textural variations have been related to minor climatic fluctuations.

Limestone facies occur throughout the section whereas the shale facies predominate below 240 masl in the Christina Member. The biohermal facies occur only in the Moberly Member above 240 masl.

2. Several intraformational unconformities have been identified which suggests that structural continuity exists across the lease. These surfaces have been identified throughout the sequence and correlate over substantial distances in section. Each unconformity represents a period in Paleozoic time that was characterized by uplift and localized surface karstification.

3. Devonian-Cretaceous paleotopography is complex with a large amount of relief. Maximum relief at the SANDALTA lease is approximately 100 metres. Early Cretaceous fluvial erosion is considered to contribute up to 90 metres of this relief. Numerous wide, deep drainage channels were identified and often infilled with unsorted, alluvial materials such as sands, silts and clays.

Surface karstification and Prairie Evaporite subsidence are two additional mechanisms believed to have contributed up to 20 metres of paleotopographic relief. The overall paleotopographic character is envisaged as a rolling, undulating karst surface with numerous deeply incised drainage channels. Extensive subsurface caverns or voids were not generally supported.

4. Intraformational hardground surfaces were not regionally extensive and could only be employed in local stratigraphic correlations.

5. No compressional folding or brittle faulting is apparent at SANDALTA. Stratigraphic continuity discounts large vertical offsets, however strike-slip movements would not be readily detected in section. Normal or thrust dip-slip faulting at a scale greater than the SANDALTA lease would also not be detected.

6. Local collapse pipes are sporadically located and do not appear to be related to early Cretaceous drainage channels. That is, early Cretaceous drainage, although likely influenced by paleotopography, does not appear to be related to Prairie

Evaporite subsidence. There is no evidence to suggest that a hydrogeologic or structural relationship exists between the collapse pipes and early Cretaceous fluvial drainage. Collapse pipes are randomly located and thought to be a function of early preferential solution of the Prairie Evaporite.

4. KARST, EROSION AND WEATHERING FEATURES

4.1 Dissolution Features and Distribution

4.1.1 Aqueous Corrosion

Karst refers to an irregular limestone topography characterized by sinkholes and caverns, occurring as a result of carbonate dissolution by chemically active surface waters (Sweeting, 1972; Jakucs, 1977). The dissolution process is not a physical process. Physical erosion and weathering are discussed in Sections 4.2 and 4.3 respectively. Aqueous corrosion or solid dissolution involves the molecular removal of calcite by one of three reactions (Jakucs, 1977):

1. carbonate dissolution in pure water
2. hydrocarbonate dissolution in carbon dioxide enriched waters.
3. carbonate dissolution in other chemical reagents such as soil acids.

Carbonate dissolution is based on the balanced reaction:

$$CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-}$$

Dissociation of calcite into the constituent calcium and carbonate ions depends primarily upon pore fluid chemistry. The reaction occurs only in pure solutions. Since pure meteoric waters are volumetrically insignificant, the carbonate dissolution mechanism is not a dominant corrosional force. Moreover, the reaction occurs much more slowly in pure waters than in acidic solutions where the reaction is catalyzed (Jakucs, 1977).

Conversely, hydrocarbonate dissolution is predominant and widespread. This process is governed by the equilibria of dissolved carbon dioxide or the acidity of the pore fluid. Numerically, the maximum CO_2 concentration was given by Mason (1966):

$$[CO_2] = (1.9634)\ L\ p$$

where $[CO_2]$ = concentration of CO_2

p = partial pressure of CO_2

L = temperature dependent solubility of CO_2

The temperature and pressure dependence of the reaction is thus apparent, noting that CO_2 solubility increases with decreasing temperature. The concentration also increases with increasing partial pressure in accordance with Henry's and Boyle's Laws. CO_2 concentration is also affected by equilibrium reaction time, gas-fluid interface effects, gas turbulence, fluid agitation and other unquantified parameters.

Hydrocarbonate dissolution occurs in four distinguishable stages following the creation of carbonic acid from dissolved CO_2 (Jakucs, 1977).

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

The first reaction involves simple calcium carbonate dissolution:

$$CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-}$$

This reaction is accompanied by the association of carbonate ions (CO_3^{2-}) with dissociated hydrogen ions (H^+) from the carbonic acid. These two reactions occur instantaneously.

$$H_2CO_3 \rightleftharpoons 2H^+ + CO_3^{2-}$$

The third phase requires minutes to complete and involves the depletion of local CO_2. The final phase, which involves the adsorption of free CO_2 from the atmosphere, generally requires hours or days to complete. Thus, the corrosive potential of hydrocarbonate dissolution is dictated by the "aggressivity" of the infiltrating solvent. This in turn is a function of its excess dissolved CO_2. The solubility of calcium carbonate therefore increases with increasing acidity or decreasing pH. At pH values greater than 9.5, the formation fluids are basic and carbonate dissolution predominates (Jakucs, 1977). In general, groundwaters possess a significantly higher CO_2 content and thus greater aggressivity than surface meteoric waters. This is due to the higher partial pressure of CO_2, higher temperature and organic acid content.

The third solution mechanism that may have affected the Waterways is that of dissolution in other chemical reagents. Soil acids such as humic, formic, acetic, fulvic and oxalic acid are produced by the aerobic or anaerobic decay of floral and faunal remains. They interact with the solid phase carbonates by direct chemical exchange which is again controlled by solvent pH. Some decay processes also contribute to an increased CO_2 concentration in the solvent. Inorganic acids such as nitric, sulphuric and carbonic acid may also be produced by the weathering of sulphate minerals or other compounds.

Secondary controls on the dissolution process include lithologic character, local rock mass structure, regional hydrological and hydrogeological effects and the in-situ state of stress. In particular, a high clay content may serve to retard karst development by filling fractures and thus reducing formation permeability. Similarly, regional structural features such as faults may retard or accelerate the dissolution mechanism by affecting permeability. Formation joints commonly lead to preferential solution and the development of kluftkarren (see Section 4.1.2). Likewise, regional hydrogeologic gradients may influence preferential solution in the direction of flow. Any one of these factors may be additionally influenced by a change in the local stress field due to tectonic or other structural occurrences.

4.1.2 Core-Sized Features

Core-sized solution features include subvertical pipes or karren and occasional inclined or subhorizontal cavities (Plate 4.1). These features are concentrated below erosional unconformities and may be characterized in terms of their degree of solution or maturity. In particular, it is proposed that solution features developed about intraformational unconformities are relatively immature. These unconformities represent short erosional periods whereupon uplift, surface exposure and mild dissolution occurred. The current joint system had likely not developed and surface dissolution is believed to have been topographically and lithologically controlled. That is, surface relief, clay content and

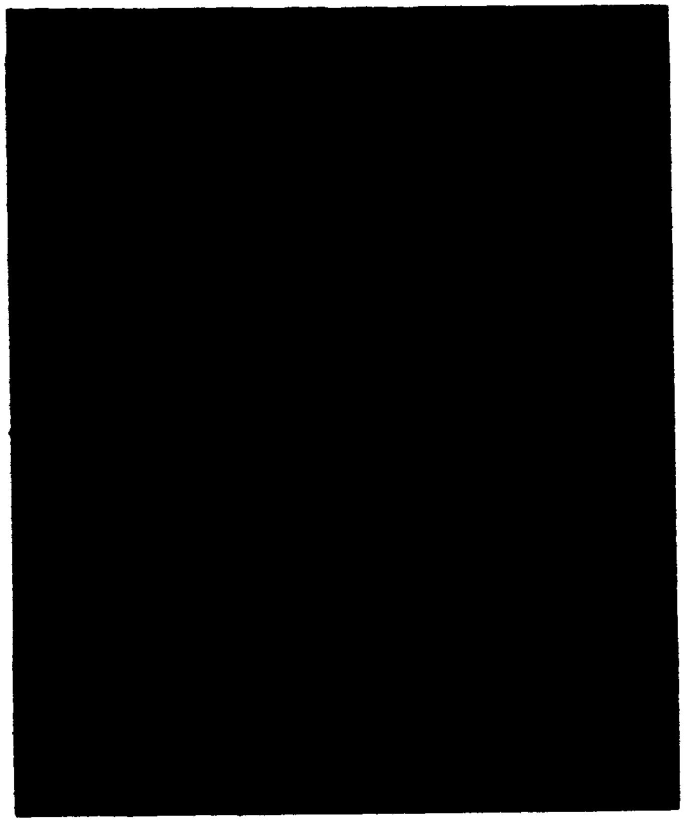


Plate 4.1: Typical Solution Pipe or KluftKarren (CH.135)

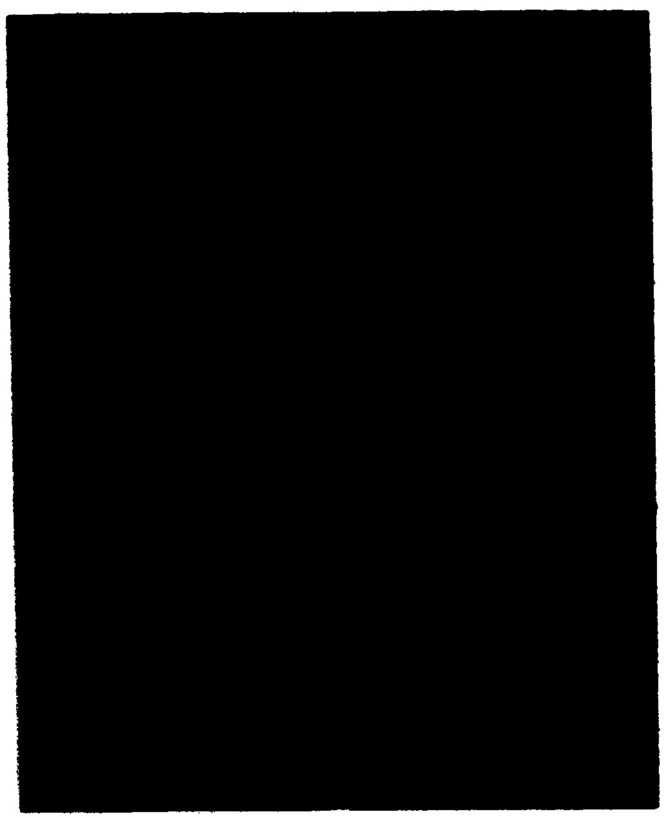


Plate 4.2: Paleoresidual Clays with Limestone Fragments and Sphaerosiderites (CH.191)

texture are thought to have had a greater influence upon karst development than structural influences such as joints. This effect is especially pronounced in the biohermal limestones of rock type D where high primary permeability is considered to have accelerated the dissolution process.

Surface pipes may have developed in random formation fractures, however no predominant joint system is believed to have yet formed. These immature pipes and cavities commonly define an apparent "active zone" within a few metres of the intraformational unconformity. They were usually infilled with light green residual clays. These clays were highly plastic and often contained small (<1 cm) chips of microcrystalline limestone and sphaerosiderites (Plate 4.2). They are believed to be residual paleosols that originated on the erosional surface and were subsequently swept into nearby solution cavities (see Section 4.3.3). Infilling may have served to further retard karst development. No sand infillings were observed adjacent to intraformational unconformities.

In contrast, solution features developed at the Devonian-Cretaceous unconformity are relatively well developed. The "active zone" extends to many metres below the contact and a moderately well developed weathering profile was observed (Plate 4.3). Karst features are thought to have been structurally controlled which led to

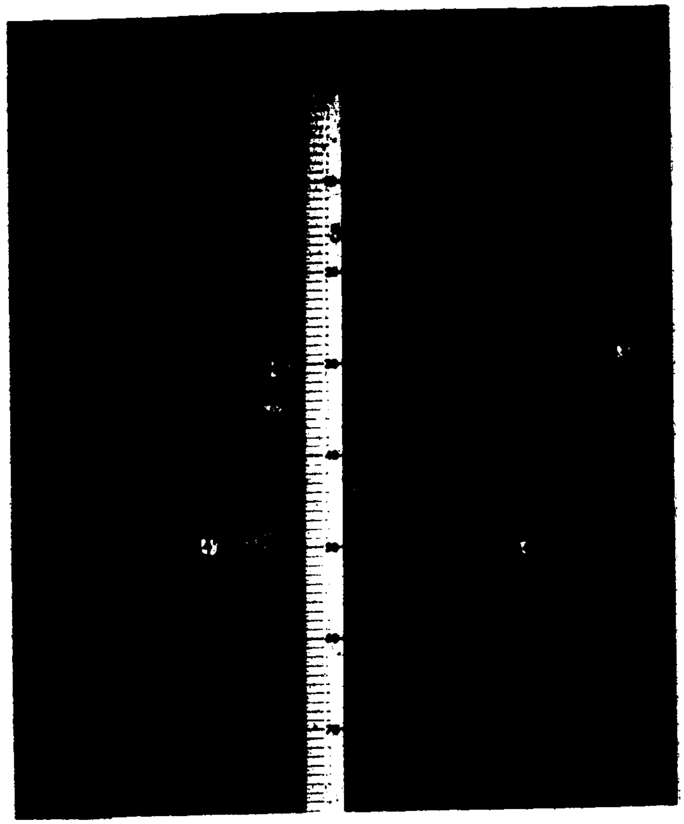


Plate 4.3: Typical Weathering Profile (CH.163)

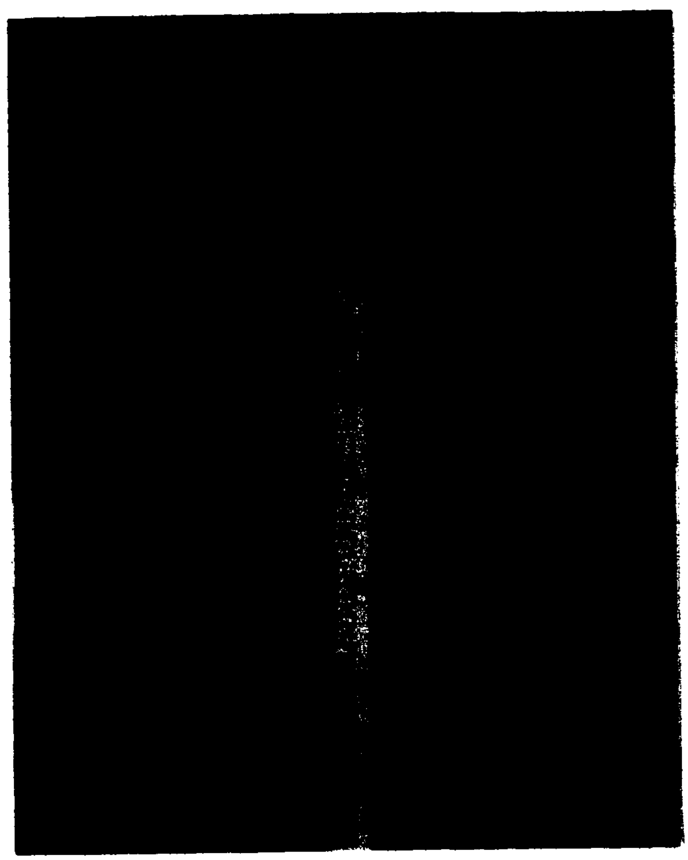


Plate 4.4: Sand Filled Solution Pipe (CH,143)

the development of kluftkarren (Sweeting, 1972). Kluftkarren are formed by the preferential corrosion of limestone along fractures. Since Waterways joints are predominantly subvertical, the resulting kluftkarren are also considered to be characteristically subvertical (Plate 4.1). This is supported by both core and field observations. Subhorizontal features are less significant due to the proposed structural control, however outcrop exposures revealed some bedding controlled cavities (see Appendix D). In addition, corehole 150 displayed a thick (approx. 10 m) section of non-marine alluvium at depth, which may be interpreted to represent a large infilled subhorizontal cavern.

Pipes near the Devonian-Cretaceous surface also revealed a high proportion of sand fillings. Again, these sands were observed both in core and the field where they were underlain by older, light green residual clays. The sands are believed to be Cretaceous deposits which were subsequently infiltrated with bitumen (Plate 4.4).

In summary, although the Devonian-Cretaceous karst is considered to be more highly developed than any of the intra-Devonian surfaces, all Waterways solution features are considered to be relatively immature.

Core-sized features were found to be limited to a shallow active zone less than 5 metres below the unconformity. Contacts were commonly highly scoured with little or no paleosol. This character reflects a relatively short-lived, high energy erosional environment where there was little opportunity for holokarst development. In Section 4.1.4, the establishment of early Cretaceous fluvial drainage is considered in relation to karst development.

4.1.3 Deep-Seated Regional Features

Despite an overall lack of structural information below 200 masl, several general conclusions may be drawn from overlying core features.

Firstly, large scale (>10 m diameter) solution features appear to be dominated by the removal of the Middle Devonian Prairie Evaporite Formation. There is no core evidence to suggest that solution pipes larger than 10 metres exist within the Waterways. Instead, numerous collapse breccias were observed (Figure 4.1) and are considered to represent vertical collapse pipes or sinkholes resulting from a loss of Prairie Evaporite support. They are not thought to represent dolines which were initiated at the surface and were subsequently infilled with collapsed sidewall material (Figure 4.1). All large scale aqueous corrosion is therefore perceived to have occurred within the Prairie Evaporite. Little dissolution is thought to have occurred within the

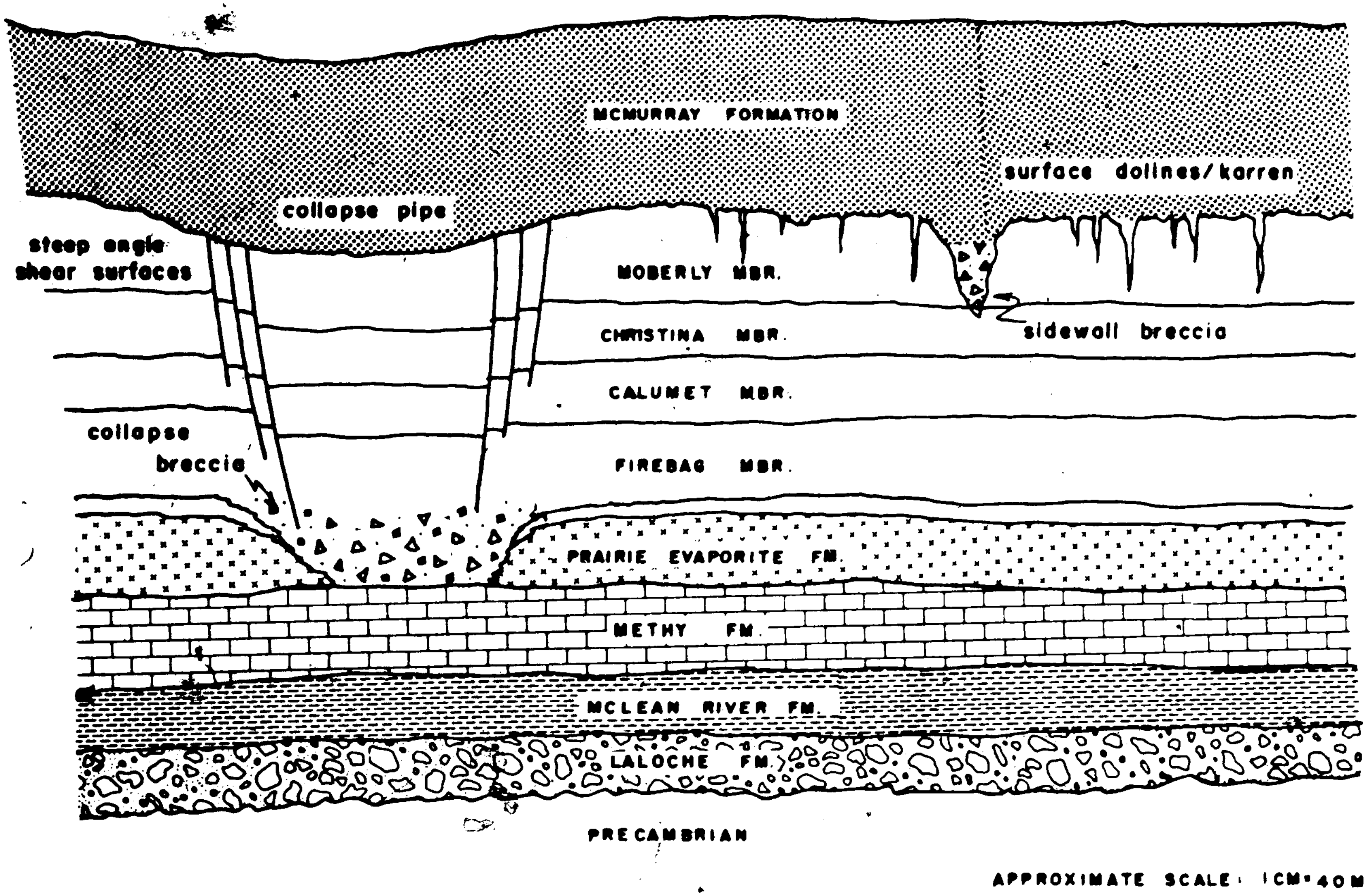


FIGURE 4.1: IDEALIZED REPRESENTATION OF COLLAPSE PIPES AND SOLUTION DOLINES

Waterways except at the time of intra-Devonian exposure and immediately preceding McMurray deposition. The relative immaturity of surface karst as described in Section 4.1.4 is compatible with the concept of deep-seated collapse pipes.

In general, deep-seated collapse features are mechanically feasible only if the Prairie Evaporite cavities are larger than a critical span which is expected to be a function of the stress state, material features and depth of overburden. Coates (1981) stated that no predictive capabilities have been developed to account for vertical "chimneying" of block caving, however Dunn (1982) has characterized Prairie Evaporite cavities in Saskatchewan on a scale of 45 metres. This perception of collapse cavities is incompatible with the large (<400 metre) diameter structures proposed in Section 3.6.4. Dunn (1982) envisaged subsidence of the Middle Devonian Dawson Bay Formation resulting in steeply dipping beds up to 65°, but not overturned, abundant steep-angle fractures and vertical strain features. Tectonism was not considered responsible for these deformations. The solution of large cavities was addressed by Dunn (1982) and attributed to continual flushing of the formation. Stress arching is expected to have preceded overstressing and collapse.

Further support for the proposed collapse mechanism may be extracted from the nature of the observed collapse breccias. They consistently display a lack of apparent transportation or reworking. Former bedding planes may be established and the characteristic light green, surface residual clays are absent (Plate 3.10). These breccias are again distinct from the syndepositional intraclast breccias of rock type C. The distribution of disturbed borehole structures is presented in Figure 4.2. Not all breccias are expected to represent deep-seated collapse pipes.

Finally, the presence of small circular lakes as described by Ozoray (1977) suggests deep-seated influence. Ozoray (1977) found lakes in the Bitumount area to be deep, circular features with diameters up to 150 metres. They were also arranged along gently curved lineaments which Ozoray (1977) suggested were influenced by the regional morphotectonic pattern. Hackbarth (1978) also noted the regional alignment of collapse pipes in an arcuate band extending across northeastern Alberta. This trend was considered to coincide with the western extent of Prairie Evaporite solution. Benthin (1973) represented three episodes of collapse; the pre-tar, post-tar and modern periods, of which SANDALTA may have been affected by the latter two only (Figure 4.3). Benthin's (1973) model is incompatable with the early post-depositional solution proposed herein.

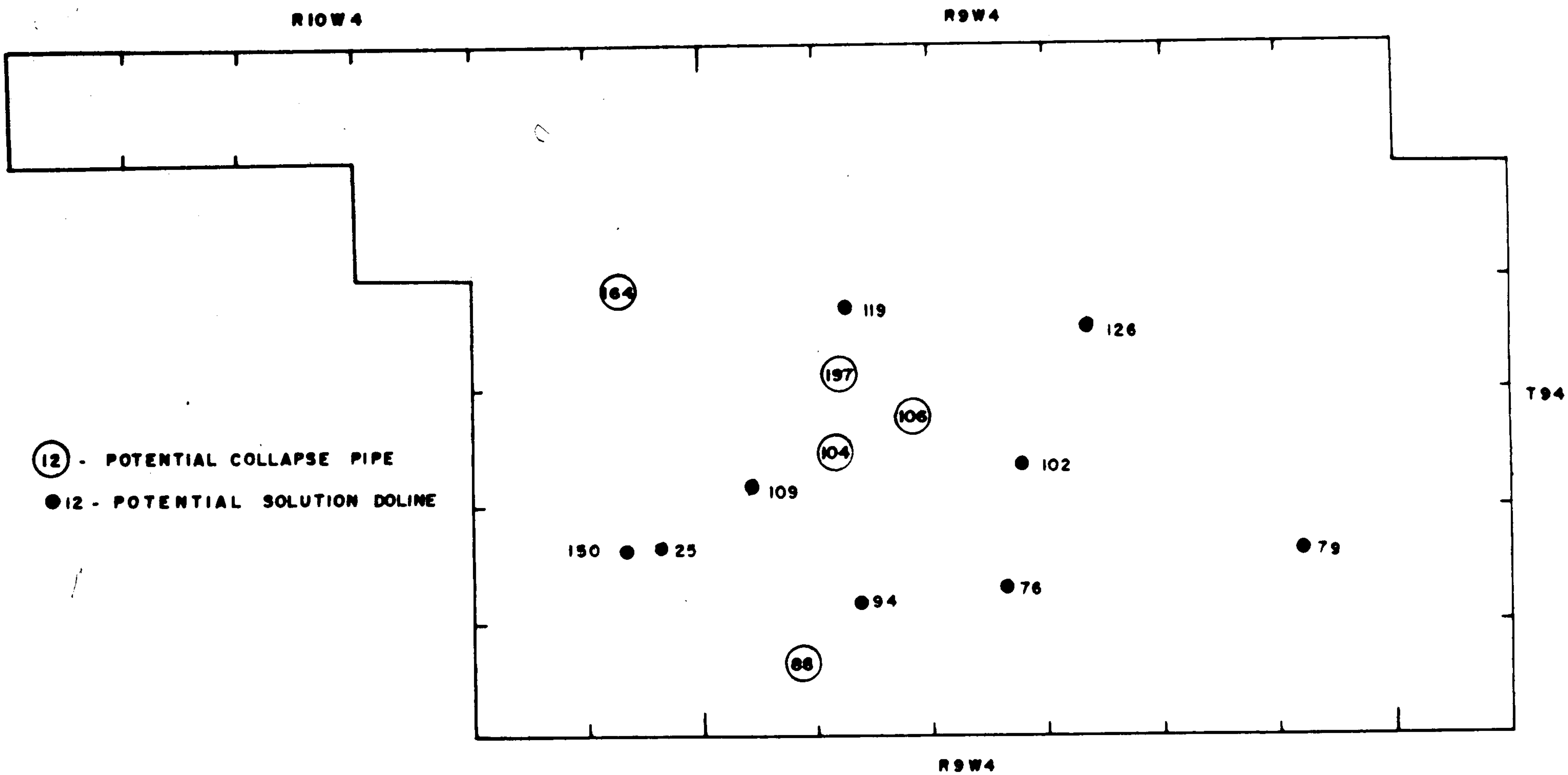


FIGURE 4.2: DISTRIBUTION OF DISTURBED BOREHOLE SECTIONS AND POTENTIAL COLLAPSE STRUCTURES

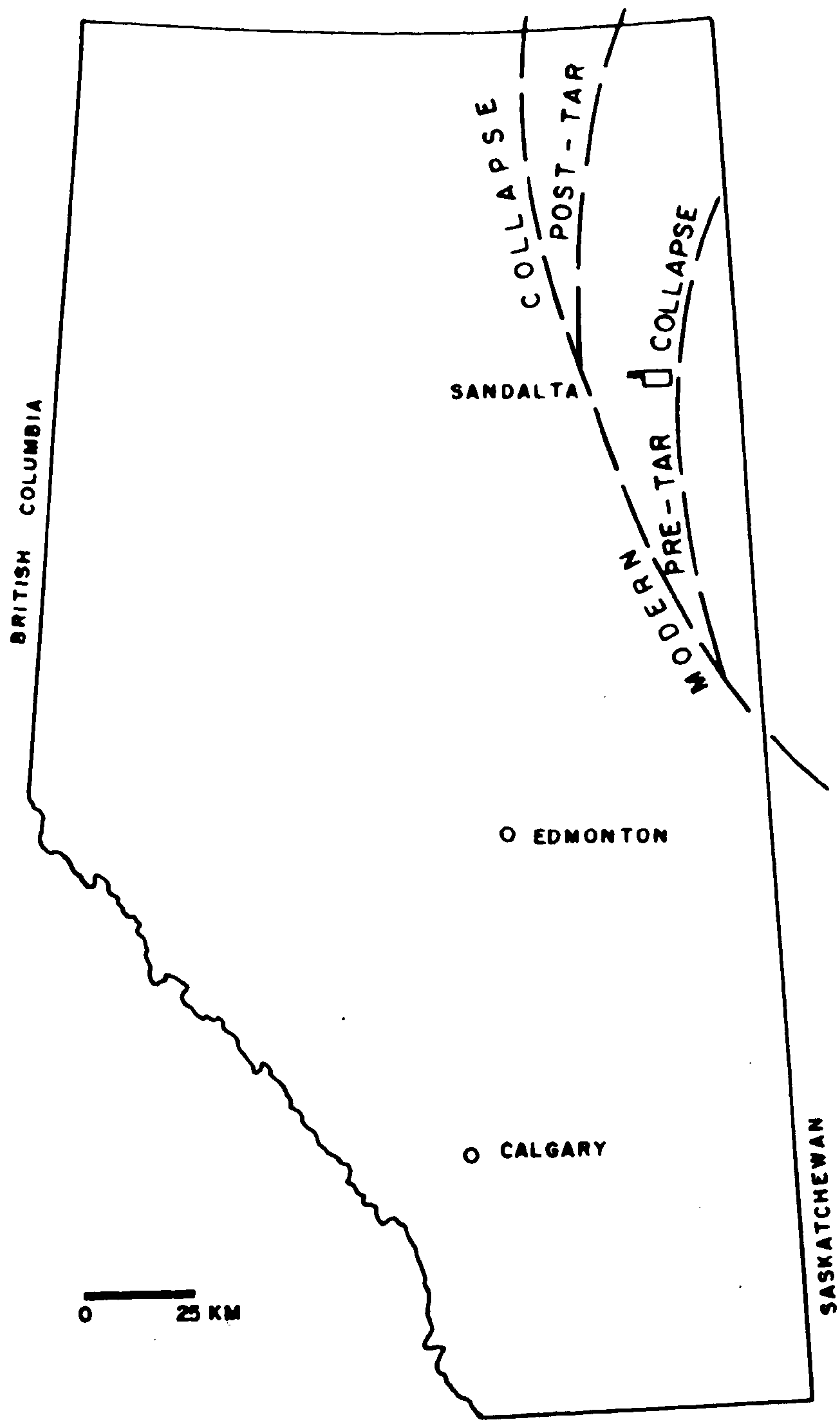


FIGURE 4.3: EPISODES OF SALT COLLAPSE (after Benthin, 1973)

GCRI (1981) have confirmed that Prairie Evaporite thickness in Township 95, Range 10 is zero in at least one location. This suggests that evaporite solution and subsidence may be complete. Although no boreholes investigated the Prairie Evaporite at SANDALTA, if solution is complete, then no further collapse is expected.

The second potential deep-seated structural feature related to Prairie Evaporite solution is that of regional faulting. There is presently no corehole or stratigraphic evidence to either support or refute this mechanism, however the subsidence of Upper Devonian materials over a retreating solution edge is expected to involve considerable brittle deformation. Figure 4.4 depicts two potential faulting mechanisms; that of regional normal faulting and graben faulting. The potential for Precambrian faulting is also recognized, however it is not a consequence of Prairie Evaporite solution.

Graben structures have been proposed primarily on the basis of trough-like depressions oriented north-south across the SANDALTA lease. Sections A-A' to C-C' in Appendix B suggest that this structure is an early Cretaceous fluvial channel and not a massive block fault. This explanation is supported by the lack of disturbed structures below the proposed fault zone and an

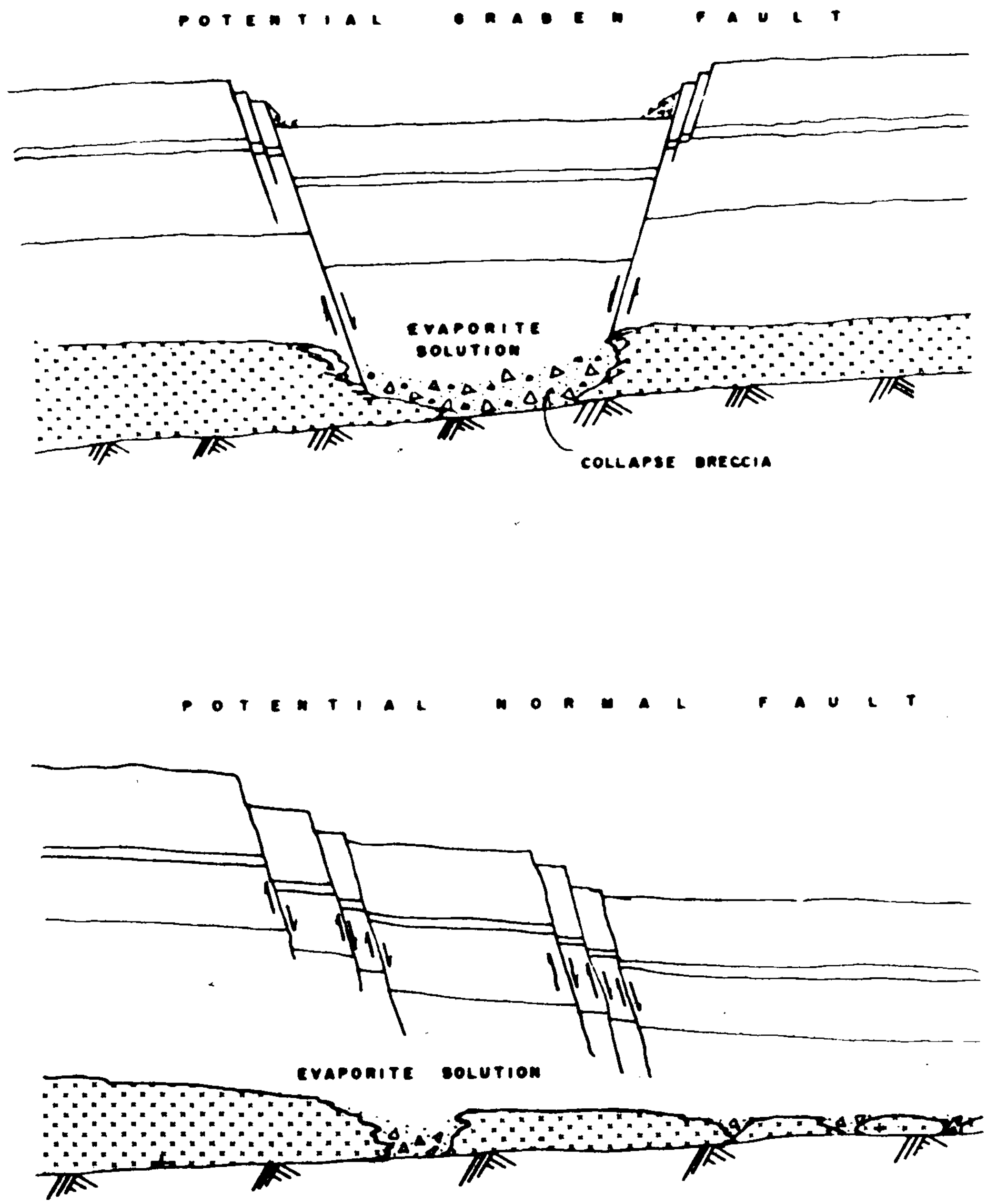


FIGURE 4.4: IDEALIZED BRITTLE DEFORMATIONS ASSOCIATED WITH PRAIRIE EVAPORITE SOLUTION

absence of obvious stratigraphic offsets. Furthermore, the channel correlates well with previously published drainage patterns, (Stewart, 1963) and exhibits Cretaceous infill materials that are fluvial in origin. Despite these features however, the potential for regional graben faulting cannot be dismissed.

Thus, it is believed that major topographic depressions are a function of early Cretaceous fluvial erosion and not deep-seated faulting. Regionally, Prairie Evaporite solution is considered to be responsible for substantial subsidence, however there is no evidence to suggest that the Prairie Evaporite may have been 100 metres thick at the SANDALTA lease. Subsequently, normal faulting is the favoured brittle deformation mechanism.

In summary, deep-seated regional structures are predominated by the solution of the Prairie Evaporite Formation. Vertical collapse pipes are considered to have been early manifestations of preferential solution and are thought to have been mechanically feasible only if solution cavities were sufficiently large.

Collapse breccias were distinguished from syndepositional intraclast breccias and shallow collapse dolines. There is no core evidence to support the existence of very large (>10 m) subhorizontal caverns or liquid-filled cavities.

Regional graben faulting is also considered,

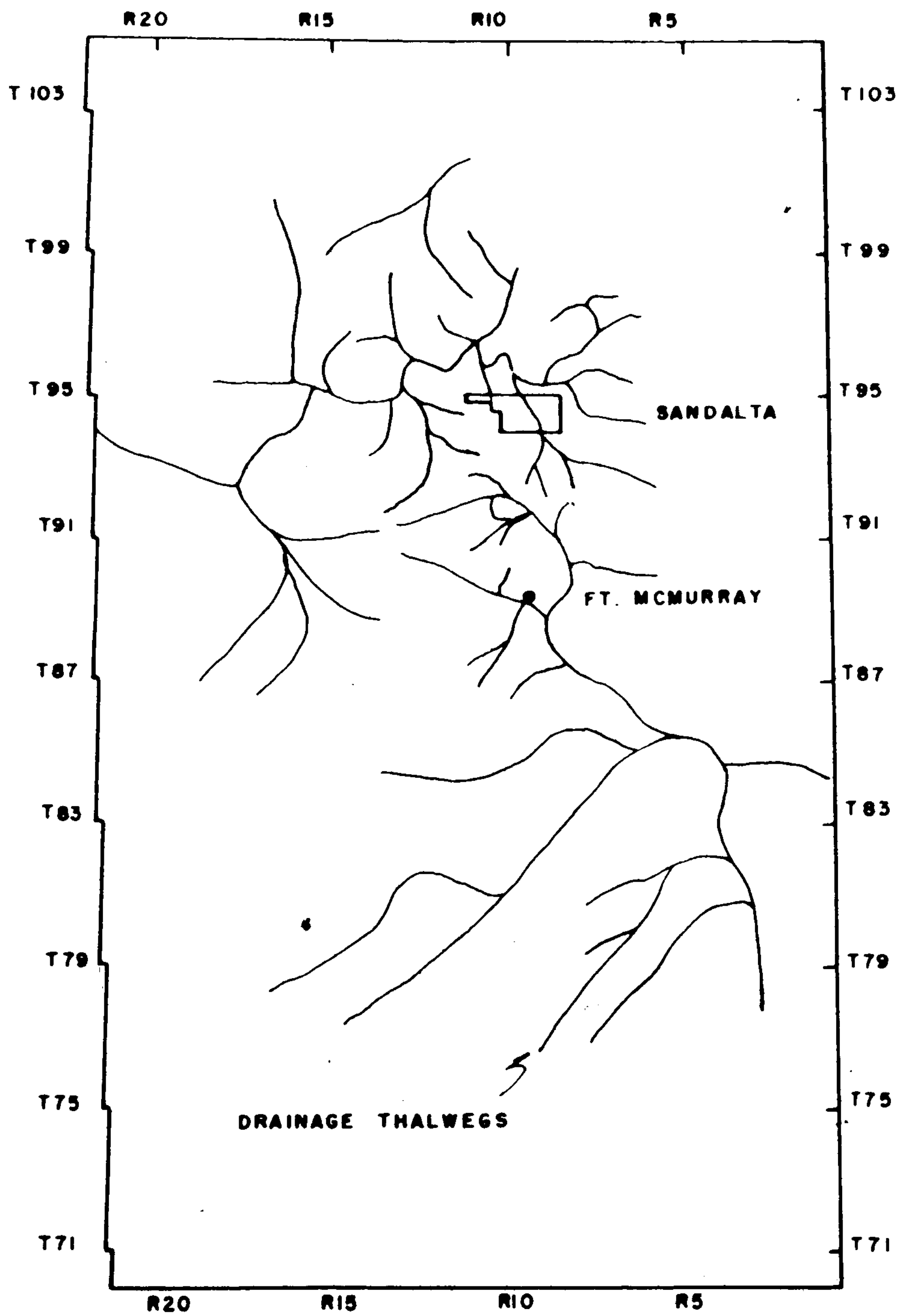


FIGURE 4.5: REGIONAL EARLY CRETACEOUS DRAINAGE PATTERN (after Stewart,1963)

however normal faulting is thought to have been more likely. There is no stratigraphic or structural evidence in the shallow core at SANDALTA to confirm either of these brittle faulting mechanisms.

4.1.4 Karst Morphogenetics

Jakucs (1977) defined karst morphogenetics as the science of the origin of karst forms. Such forms were considered to be a function of eight primary influences:

1. lithologic variance
2. climatic variance
3. hydrogeologic variance
4. tectonic variance
5. topographic variance
6. biological variance
7. chemical variance
8. time

Although each of these controls affected karst development at SANDALTA, lithologic, climatic and hydrogeologic variances are considered to have had the greatest influence.

Sweeting (1972) stated that the essence of the karst process is the sinking and circulation of surface water underground. The absence of surface water is diagnostic and, in the strictest sense, no soils or drainage streams may exist. No traditional erosional mechanisms are recognized. The purest form of karst is holokarst. The development of holokarst requires a clean, massive limestone with vertical hydraulic conductivity (usually joints) and the existence of a regional climate with adequate precipitation. Under such conditions, karstification is slow and imperceptible, but leads to the development of characteristic solution features such as dolines and karren.

Dolines are closed hollows or depressions that comprise the fundamental unit of a karst terrain. They may be bowl-shaped, funnel-shaped or well-shaped, but generally develop in surface lows where precipitation runoff collects. Collapse dolines are also defined and are characterized by steep, cliff-like walls and a high depth to diameter ratio (Sweeting, 1972).

Karren are small scale features. Kluftkarren are joint controlled pipes at a scale of a few centimetres to 4 metres. They commonly develop into deep, cleft-like ruts that are oriented parallel to the dominant joint system.

Williams (1980) characterized karsting in the Waterways in terms of three features:

1. regular subsidence
2. massive collapse

3. cone karst (fossil buried karst)

Williams' (1980) regular subsidence referred to Prairie Evaporite solution and subsequent regional settlement. Massive collapse referred to the development of collapse holes or pipes as they are referred to in the present study. Williams (1980) envisaged these holes to be as large as 15 km in diameter. The present author considers them to be characteristically less than 400 m in diameter (Figure 4.1).

Williams' (1980) buried cone karst referred to the development of dolines and karren on the ancient erosional surface. He noted that the extent of this karst was unknown but that isolated outcrop examples revealed small scale solution features. Williams (1980) speculated that the absence of other karst features, such as caves, may be related to the origin of the karst which was considered to be a tropical karst.

Based on the six karst categories defined by Sweeting (1972), the present author considers the Devonian-Cretaceous karst to have been a fluviokarst. Intraformational karst appears to have been holokarstic while the solution of the Prairie Evaporite Formation is strictly a buried karst.

Sweeting (1972) described fluviokarst as a karst region cut by allogenic rivers where there was less opportunity for the development of deep circulation.

Under such circumstances, surface drainage predominates and springs, river valleys and gorges are common. Caving may occur at the junction of limestone with impermeable beds. Solution is usually most intense near the valleys due to increased runoff. The area between valleys is unhindered and characteristically holokarstic. All of these features characterize the Waterways with the exception of caves. Moreover, the apparent low degree of Devonian-Cretaceous karst development is compatible with a fluviokarst environment where there was less opportunity for extensive corrosion.

In constrast, intraformational surfaces were not likely fluviokarstic but rather holokarstic. Holokarst is pure karst that is not influenced by surface drainage channels. The short-lived intraformational erosional periods are not considered to have included significant deviations from the shallow marine subenvironment. Surface karstification was likely controlled by local topography. Both intraformational holokarst and Devonian-Cretaceous fluviokarst are considered currently inactive. Alternatively, the buried karst of the Prairie Evaporite Formation is likely active. Local saline springs originating in the Middle Devonian have been documented by Ozoray, Hackbarth and Lytviak (1980). The hydrogeologic regimes of all three karst systems are distinct and independent (see Hackbarth, 1978).

In summary, three distinct karst classes may be recognized in the Middle and Upper Devonian sequence. Prairie Evaporite solution is unquestionably a buried karst whereas intraformational and Devonian-Cretaceous karsts are holokarstic and fluviokarstic respectively.

4.2 Erosional Features and Distribution

4.2.1 Cretaceous Drainage Channels

Mossop (1978) stated that the present Devonian surface was "characterized by considerable topographic differentiation". This was attributed to three factors:

1. normal physiographic sculpting; responsible for approximately 30 metres of relief
2. warping of the Devonian strata in response to differential evaporite solution; responsible for up to 20 metres of relief
3. local karst development; sinkholes may be tens of metres deep

The present study confirms these three mechanisms but adds that relief due to "normal physiographic sculpting" is at least 90 metres in the SANDALTA locale. In addition, local karst development is distinguished from deep-seated collapse pipes or sinkholes as described in

Section 4.1.3. Relief due to local karst development is considered negligible relative to collapse subsidence and erosion. Warping is a more regional consequence of evaporite solution. Mossop (1978) concluded that the irregular topography of the Devonian surface may render construction at the base of the McMurray very difficult. High resolution resistivity mapping was considered more promising than seismic methods in delineating surface detail.

According to Rudkin (1964), early Cretaceous time was characterized by an overall subsidence of the interior plains of North America. [illegible] the Athabasca region, this permitted transgression of the northern Boreal Sea. The resulting transient fluviodeltaic environment was thought to have been a relatively high energy system. This system was ultimately responsible for the deposition of the mature quartz sands of the McMurray Formation. Preceding this event however, was an extensive net erosional hiatus of approximately 250-300 million years. Late Paleozoic and early Mesozoic sediments were deposited, however were ultimately eroded prior to Early Cretaceous time (Mossop, 1980).

It is generally accepted (Stelck, 1975) that Precambrian tectonic divisions exercise geographic control on the distribution of Cretaceous sands throughout Western Canada. Stewart (1963) attributed ridges on the Devonian unconformity to block faulting in the Precambrian basement, however no direct evidence was provided. A northwesterly draining dendritic pattern was mapped (Figure 4.5) and reflected the structural ridge control of early Cretaceous drainage.

Martin and Jamin (1963) also considered paleodrainage and emphasized a highly dissected topopgraphy throughout the McMurray region. They quoted slopes as high as 360 feet per mile (68 m/km) and identified two major strike ridges. These ridges were thought to be erosion-resistant lithologies which were crosscut and offset by a major north-northeasterly striking fault (Figure 2.3). Two major drainage systems were thus defined, draining northward and southward of a central cuesta bridge in Townships 89 to 91. Drainage direction at the SANDALTA lease was therefore northerly. Secondary fault or fracture control was also identified and gave rise to the development of accompanying obsequent and resequent streams. Martin and Jamin (1963) further characterized these streams as narrow, closely spaced (ave. 13 km) and wide, widely spaced (ave. 47 km) streams respectively.

Although little is known of the character of the Devonian surface immediately preceding early Cretaceous erosion, the predominance of fluvial scouring at SANDALTA is readily identified in Sections A-A' to C-C', Appendix

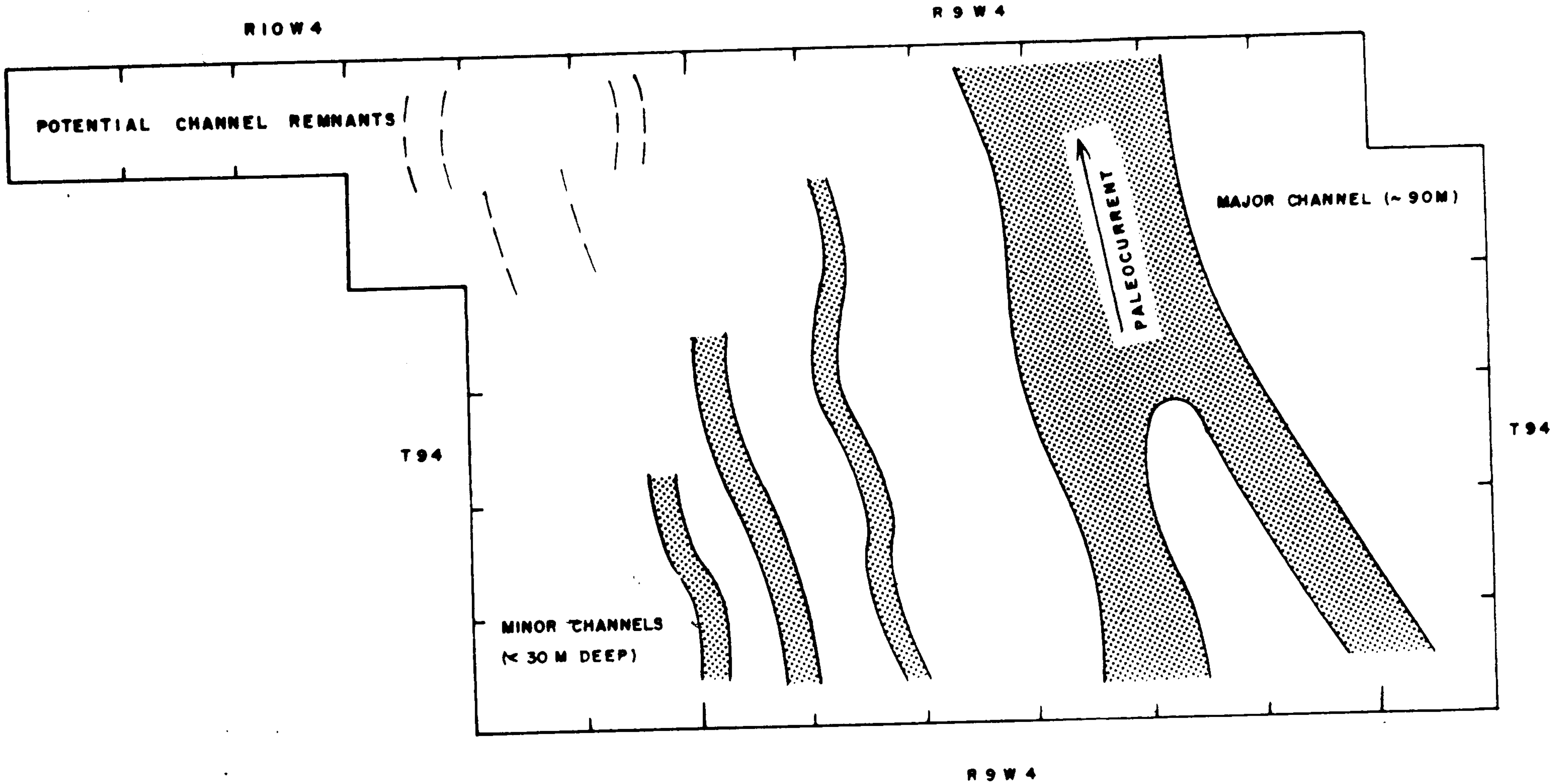


FIGURE 4.6: LOCAL EARLY CRETACEOUS DRAINAGE CHANNELS

B. These sections display scour channels up to 90 metres deep which are not underlain by disturbed or slumped materials. Moreover, these depressions are continuous in plan and are commonly infilled with unsorted alluvium. They are not considered to represent solution collapse features, local warping or graben structures.

Figure 4.6 also illustrates that at SANDALTA, all channels align north-south and do not meander significantly. One deep continuous channel occupies the eastern half of the lease and appears to separate into two distinct subchannels in the southeastern corner. This tributary pattern suggests a northward paleocurrent direction. The primary channel is up to 90 metres deep and 3-4 kilometres wide. This does not imply that the occupying river was of equivalent dimensions. The non-meandering or youthful state of the channel is consistent with its proposed high energy character. There is no evidence of valley rebound strains due to unloading.

Three additional minor channels were located in the western half of the lease. Again, these channels are oriented north-south with a northerly paleocurrent direction. Their depth does not exceed 30 metres and they are approximately 1500 metres wide. Several potential channel remnants were located at other locations however they did not correlate well in plan and thus may only represent discontinuous pre-Cretaceous lows.

4.2.2 Alluvial Materials

Mossop (1978) also categorized the nature of basal McMurray materials and defined two basic lithologies:

1. poorly sorted coarse grained sands and gravels
2. fine grained organic shales, silts and lignite coals

These materials had previously been described by Carrigy (1963, 1966, 1973), James and Oliver (1978) and Dusseault and Morgenstern (1978). Mossop (1978) emphasized that these materials were not present in most locations and that the bitumen saturated McMurray sands commonly lay directly on the scoured limestone surface.

In general, only the fine-grained alluvium was observed during the present study. These materials were characteristically dark brown to black, fine-grained sands, silts and clays with a high organic content (Plate 3.14). They are readily distinguished from the light green, plastic silty clays that characterize the immediate Paleozoic surface and solution pipe infillings. These latter materials are considered to be reworked Devonian micrites or paleosols (Plate 4.2). The basal McMurray alluvium varied in thickness up to 15 m and commonly infilled Devonian topographic lows or fluvial channel flanks. Minor bedding was occasionally observed. Dusseault and Morgenstern (1978) described the engineering properties and behaviour of these materials in detail. They are distinguished from paleoresidual materials on the basis of clay mineralogy in Section 4.3.3.

Although coarse grained sands and gravels were not observed in the study core, they are believed to exist and may form thin, sinuous deposits at the base of various early Cretaceous channels. Regional transgression following downcutting is considered to have resulted in low energy flooding thereby favouring fine-grained deposition.

4.3 Weathering Features and Distribution

4.3.1 General

Williams (1980) observed a wide range in the degree of weathering throughout the Waterways; from faintly to extremely weathered. He noted that in outcrop, weathering commenced along bedding and joint discontinuities and progressed inward toward intact rock.

During the present core study, the majority of weathering features were observed about the various intraformational unconformities. Discoloration and a mild loss of texture were observed (Plate 4.3) however this rarely extended beyond 1 metre below the unconformity. Such features represent short-lived periods of exposure during Devonian time and should be distinguished from the post-Devonian features observed in outcrop and at the Devonian-Cretaceous unconformity.

In general then, paleoweathering is relatively poorly developed. No core examples of extremely weathered fractures were observed and the development of residual paleosols is not ubiquitous. In contrast, outcrop exposures displayed a moderate to highly weathered character. Differential weathering was the most obvious feature and was pronounced in the marbly argillaceous lithologies where it led to a distinct nodular texture and rubbly talus. This texture is a consequence of the difference in degradation rates of the micritic and calcitic components of the rock mass. Field examination revealed that the argillaceous or micritic component was more susceptible and that the nodules are composed of hard, microcrystalline calcium carbonate with little or no micrite. This observation suggests that chemical degradation of the micritic component dominates Waterways weathering. The calcareous cement that binds individual particles is chemically unstable in the low pH and high Eh conditions of the terrestrial atmosphere. Bonds are dissolved resulting in an overall loss of strength and rigidity. This reduction is expected to be greatest in the more argillaceous lithologies. An accompanying reduction in the elastic modulus and an increased susceptibility to physical weathering are also expected. Physical processes such as rain, wind and freeze-thaw cycles are of secondary importance.

In summary, a low degree of weathering characterizes the Waterways at depth. Solution and erosional properties were the predominant post-depositional occurrences. In general, paleoweathering was limited to slight discoloration and loss of texture about fractures. It is concentrated immediately below intraformational unconformities. Differential weathering is well developed in surface outcrop primarily due to the susceptibility of the calcareous argillaceous matrix. Weathering is expected to contribute to an overall decrease in rock mass rigidity and strength.

4.3.2 Bitumen Infiltration

Williams (1980) thought that bitumen occurred in the Waterways as a coating or rock wall stain in joints. This observation was made however, on outcrop samples that had been influenced by stress relief, drainage and water washing. The present study reveals that at depth, bitumen occurs more commonly as a fracture infilling or pore fluid than as a residue or coating.

The maximum depth of infiltration observed was approximately 60 metres below the Devonian-Cretaceous unconformity. Below this depth, an increase in both confining stress and argillaceous content are thought to have restricted infiltration. Virtually all staining or infilling was observed in subvertical joint and boudinage fractures with the exception of occasional sandy solution pipe infillings. This feature has direct implications for the state of stress as discussed in Section 5.4.2. Although these fractures do contain small volumetric quantities of bitumen, the author considers the Waterways to be an unlikely source for the McMurray bitumen. Link (1951) and others have proposed a Devonian source, however the present author finds no support for such a hypothesis. Infiltration is apparently absent 60 m beyond the unconformity and there is no evidence of a major source rock. Biohermal units are generally small localized structures restricted to the Upper Moberly member.

The infilling of formation joints with bitumen has at least four influences as suggested by Williams (1980):

1. lubrication of joints and fractures

2. protective cushioning of asperities during shear
3. retardation of the weathering and solution processes
4. reduction of effective normal stress

Of these four effects, the latter two are considered to be of greatest overall consequence. The presence of bitumen in formation fractures has undoubtedly caused a substantial decrease in vertical permeability since infiltration. This in turn, is likely to have retarded the development of buried karst from percolating groundwaters. This influence may be mitigated if enhanced recovery injections mobilizes the bitumen. Intraformational karst features are not thought to have been affected by bitumen infiltration because they formed prior to Middle Cretaceous time. Mossop (1980) considered this to be the time of bitumen migration into the McMurray Formation. Surface weathering may also have been retarded by bitumen staining in formation fractures.

The reduction of effective normal stresses, although not a weathering concern, is a consequence of bitumen infiltration. In an undrained state, MAISP fluid injections may induce substantial pore fluid pressures which in turn reduce normal effective stresses. The effect of this occurrence is a destabilization of the rock mass as the overall shearing resistance along fractures is decreased. The lubrication of joints and the cushioning of asperities as described by Williams (1980) are considered to be minor effects. They do not contribute to a state of instability but may influence deformations once yielding has commenced.

Other fracture infillings were observed but were limited to recrystallized calcite and minor weathered clays. No rock flour or gouge materials were observed, but may be present in steep angle shear zones associated with collapse pipes or regional faults.

4.3.3 Paleosols

Dusseault (1977) completed x-ray diffraction tests on basal McMurray materials and revealed a strong illitic and kaolinitic predominance in the clay mineralogy with minor vermiculite and mixed layer clays. The absence of smectitic or chloritic species was interpreted to be a function of the non-diagenetic provenance of the basal materials. Dusseault (1977) also suggested that the illite-kaolinite predominance was due to weathering of paleosurficial materials prior to Lower Cretaceous transgression. Expected residual strength values of ϕ = 8°-14° were also reported based upon index tests such as Atterberg limits and activity.

Dusseault and Scafe (1979) later dated the basal materials as early Middle Albian (Cretaceous) and noted the presence of weathered paleosols on local Devonian highs. Although these authors alluded to the mutual exclusivity of the reworked paleosols and basal Cretaceous clays, the two materials were not differentiated on the basis of any test properties or measureable characteristics.

The present study proposes that the two deposits are genetically unrelated and attempts to provide this distinction on the basis of clay mineralogy. In particular, the light green plastic clays found on the Devonian surface are thought to be the result of paleogeomorphological controls which were independent of early Cretaceous influences. Those materials examined by Dusseault (1977) were of Cretaceous age and thought to be unsorted fluvial drainage deposits. They are not residual Devonian paleosols. In order to establish this distinction, x-ray diffraction tests of 14 samples were conducted (see Appendix C). Although the results of this small number of samples were not conclusive, the following observations were made:

1. light green residual clays retrieved from the Cretaceous-Devonian contact were 80%-90% illite, 10%-15% kaolinite and less than 5% chlorite. No smectites were identified,

however one sample displayed trace quantities of mixed layer clays or vermiculite (see Figure 4.7).

2. black or dark brown basal Cretaceous clays were 35%-80% illite, 20%-60% kaolinite and less than 5% chlorite. Again, one sample displayed trace quantities of mixed layer smectites or vermiculite.

3. grey, calcareous micrite retrieved from the argillaceous limestones of the Moberly member were 70%-80% illite, 15%-25% kaolinite and approx. 5% chlorite. No smectites or mixed layer clays were identified.

4. olive, marine shales retrieved from depth within the Christina member were also 70%-80% illite, 15%-25% kaolinite and less than 5% chlorite. No smectites or mixed layer clays were identified.

Based on these observations (see Figure 4.7), the following conclusions have been drawn:

1. As expected, the grey limestone micrites and olive calcareous shales possess similar clay mineralogies. This finding suggests they share a common sediment source and provides

Corehole No.	Elevation (masl)	Genetic Origin	Illite (%)	Koalinite (%)	Chlorite (%)	Smectite (%)	Mixed Layer	Quartz Feldspar
127	±116.9	alluvium	34	61	?	?	5	trace
	±122.8	micrite	72	25	3			trace
	±124.2	micrite	79	16	5			trace
	±128.9	paleosol	84	14	2			1
	±135.5	shale	78	16	5			
164	±52.0	alluvium	79	19	2			trace
	±55.7	alluvium	83	13	4			trace
	±67.0	bx. clay	79	16	5			trace
	±88.0	micrite	77	19	5			trace
	±89.9	micrite	78	18	4			trace
191	±79.9	alluvium	72	25	3			trace
	±84.8	shale	83	13	4			trace
	±86.5	paleosol	88	8	?	?	4	trace
	±94.0	micrite	73	24	3			trace

Figure 4.7: Summary of X-Ray Diffraction Tests

baseline data upon which comparisons may be made with the residual and basal Cretaceous deposits. The illitic predominance of these marine deposits was predicted by Mason (1966) who stated that the high potassium and magnesium contents of seawater promotes the alteration of montmorillonite to illite or chlorite. Furthermore, diagenesis promotes the formation of illite and chlorite and the disappearance of kaolinite and montmorillonite. The relatively high kaolinite concentrations found in test samples may subsequently be interpreted to represent relative sediment immaturity and an absence of diagenetic processes. This is consistent with the lack of other diagenetic or metasomatic features throughout the Moberly and Christina members.

2. The light green residual clays are similar in mineralogy to both the limestone micrites and calcareous shales. They appear to possess slightly higher illite and lower kaolinite contents, however the number of samples chosen for testing was insufficient to prepare a statistical analysis. The similarity in mineralogy does however

support their proposed reworked Devonian origin.

3. Basal Cretaceous alluvium displayed slightly higher kaolinite contents than any of the Devonian age materials. Again statistical analyses were not appropriate, however one sample did display approximately 60% kaolinite content. This anomalous result supports a continental weathered origin as opposed to the marine genesis of the micrites and calcareous shales. Additional vermiculite or mixed-layer clays were also identified which were not observed in the calcareous shales or limestone micrites.

4. The absence of significant amounts of chloritic or smectitic species confirms the lack of diagenetic processes since deposition.

Thus, although these results may only be considered preliminary, the presence of anomalous clay mineralogies in the basal McMurray materials suggests that Cretaceous age alluvium may be differentiated from reworked Devonian residuals. Clay mineralogy is considered to be an effective criterion by which these materials may be distinguished and further statistical studies are warranted. In conjunction with other geological features such as lignite content, bedding and heavy mineral content, these materials should be readily distinguished.

In summary, paleosols are reworked Devonian micrites or silty clays that display a homogeneous, plastic character. They are commonly sideritic and possess a unique light green ferrous colour. The paleosols are highly illitic and commonly infill surface karren or solution pipes. They form a thin mantle atop the immediate limestone surface and are usually overlain by unsorted Cretaceous alluvial clays, silts and sands.

5. GEOTECHNICAL CONCERNS

5.1 General

Geotechnical interest in the Waterways Formation is primarily concerned with the response of rock mass strength, deformability and permeability to imposed changes in the in-situ stress field. Such changes may be due to open pit mine excavation, tunnelling or thermal alteration of the limestone due to steam injection. This chapter reviews rock mass properties and assesses the influence of the preceding geological features upon open pit and mine assisted in-situ recovery projects.

5.2 Rock Quality Assessment

5.2.1 Intact Rock Properties

Williams (1980) completed extensive property and behavioural tests on both intact rock and rock mass discontinuities and concluded that discontinuities become the overriding concern for the strong intact rocks. Both discontinuities and intact strength were considered important for the argillaceous lithologies. Index properties such as specific gravity, mineralogy and clay-carbonate content were evaluated and supplemented with geotechnical test data including uniaxial compressive strength, uniaxial tensile strength, triaxial compressive strength, deformability and various toughness, hardness and durability indices. Mechanical properties of the intact rock are summarized in Figure 5.1. The salient observations are reproduced below:

1. Measured clay contents substantiated visual estimates. Test values ranged from less than 5% in the massive crystalline limestones to greater than 50% in the nodular and finely interbedded lithologies.
2. Measured porosity values were very low (<1%) and specific gravity for all lithologies averaged 2.5-2.6.
3. Ultrasonic P-wave velocities were significantly lower in the more argillaceous lithofacies. Recorded values ranged from 2970 to 5600 m/sec indicating a moderately well cemented, continuous rock mass.
4. Unconfined uniaxial compression tests revealed a general decrease in strength with increasing clay content. Thus, the massive crystalline limestones displayed the greatest uniaxial compressive strength while the nodular and interbedded lithologies were generally weaker.

Laboratory Test	Massive Crystalline Limestone: Biolithic	Massive Crystalline Limestone: Aphanitic	Nodular Limestone: High Clay	Nodular Limestone: Low Clay	Shaly Limestone: Disseminated Micrite	Shaly Limestone: Banded Shale Limestone
Clay Content (%)	3%		18%	3.9%	25%	61%
Specific Gravity (Average Value)	2.562	2.521	2.560		2.535	
Porosity (%)	0.33–1.1%	0.5%	0.71–0.97%		1.1%	
Sonic Velocity ($m/sec \times 10^6$)	4730	5340	3500		2970	
Vicker's Harness No.	141	1	(1-2) nodules	(3-4) matrix	106.5	2–5
Uniaxial Compressive Strength (Average - Mpa)	59.5 ± (dry) 89.6 ± (sat) 135 ± (sat)	131.7 ± (dry) 140.0 ± (dry) 106.0 ± (sat)	39.8 ± (dry) 44.1 ± (dry)		75.6 ± (dry)	65.1 ± (dry) 45.2 ± (dry)
Triaxial Cohesion (Mpa)	21 (dry)	13.8 (sat)	10 (dry)		11.7 (dry)	
Double Shear Cohesion (Mpa)		10.6–17.6 ± (along bedding)	8.8 - 15.2 ± (along bedding)			
Young's Modulus (E) (Mpa)	53740 ±	38050±	23650±		11410±	
Poisson's Ratio	0.29		0.13		0.205	
Tensile Strength Direct Pull (Mpa) Brazilian (Mpa)	 5.75–6.8± 3.78–5.97±	 3.55–5.22± 3.35	 3.48–3.65±		 2.85–4.31±	
Swelling Test (%)						1.24–9.0

FIGURE 5.1: SUMMARY OF GEOTECHNICAL TEST DATA ON INTACT ROCK (after Williams, 1980)

5. Tensile strength parallel to bedding exceeded that perpendicular to bedding. In addition, fully saturated samples displayed a significantly lower tensile strength than dry samples.
6. Mohr envelopes derived from triaxial compression tests revealed that massive crystalline limestone had the highest strength of all lithologies at all stress levels. Biolithic limestone displayed a higher strength than aphanitic limestone at low stress levels, however both were characterized by concave downward envelopes which suggest strain weakening. Maximum axial strain at failure for the biolithic and aphanitic lithologies was less than 1%. Cohesion intercepts of 10-20 Mpa were also recorded. Due to their heterogeneous textural character, the nodular limestones yielded highly variable test results and poorly defined Mohr envelopes.
7. Double shear tests yielded cohesive intercepts similar to those determined from triaxial testing. Again, cohesion parallel to bedding exceeded that perpendicular to bedding. Absolute values ranged from 8 to

17 Mpa.

8. Young's modulus (E) and Poisson's ratio (υ) were calculated from unconfined uniaxial compression tests at low stress levels. Disseminated argillaceous limestone displayed Young's moduli in the 11,000 Mpa range and Poisson's ratios of approximately 0.06 at low axial stress and 0.15 at 50% of the ultimate uniaxial load. Williams (1980) attributed the low Poisson's ratios to clay content which permits axial compression without significant lateral expansion. Biolithic limestones exhibited greater stiffness and Poisson's ratios. Test values were 45,000 Mpa and 0.24 respectively. The deformability of nodular limestone was determined at 50% of ultimate. A Young's modulus of 23,650 Mpa and a Poisson's ratio of 0.13 were recorded. Williams (1980) emphasized that the nodular limestones displayed inhomogeneous strains and that measured deformation moduli may therefore be unrepresentative.

9. Creep testing on aphanitic limestone revealed insignificant time-dependent behaviour.

10. The results of point load and impact toughness tests agreed with other analyses. The massive crystalline limestones displayed the greatest hardness and toughness, whereas the argillaceous lithologies were comparatively weak and susceptible to weathering.
11. Slake durability of the aphanitic limestones is medium high (85%). Nodular lithologies displayed slake durabilities in excess of 90%. Calcareous shales and weathered limestones exhibited substantially lower slake durabilities.
12. Free swelling tests revealed axial swell of less than 2% in the argillaceous limestones. Shale swell tests measured axial swell to 9%. Confined swelling tests on shale generated swelling pressures less than 10 kpa.

In summary, most intact Waterways lithologies are stiff and strong. They are characterized by low primary porosities and variable clay contents. Both tensile and compressive strengths are anisotropic and dependent upon clay content. Stiffness and toughness are also a function of clay content, decreasing with increasing argillaceous content.

5.2.2 Structural Discontinuities

Although intact rock properties yield significant behavioural information, secondary structural discontinuites are expected to dominate overall rock mass behaviour. Williams (1980) determined shear strength on both bedding discontinuities and formation fractures. Dry and drained direct shear tests on bedding planes yielded peak friction angles of 54°-65° for argillaceous and massive crystalline limestones. The argillaceous lithologies displayed the lower resistance. Post-peak angles ranged from 36° to 52°. Drained tests revealed substantial reductions in the friction angle. Peak drained values ranged from 34° to 52°. Normal loads for all tests ranged from 17-600 Kpa.

Similar direct shear tests were conducted on joint discontinuities perpendicular to the bedding plane. These surfaces had not been presheared. Williams (1980) reported drained peak friction angles from 61°-75° for the argillaceous and massive crystalline limestones. Post-peak angles of 25°-54° were also reported. Normal stresses ranged from 20-900 Kpa (Figure 5.1). Williams (1980) also suggested that the presence of bitumen coatings on joint surfaces contributed to a very low apparent cohesion. See Section 4.3.2 regarding bitumen infiltration. Williams (1980) also recorded moderate to extreme joint roughness indices, however was unable to correlate them to effective shearing angle. These observations were made from surface outcrop and contrast the planar to wavy character noted during the present study. It is expected that waterwashing of surface fractures has exaggerated observed joint asperities. Lower roughness indices may be expected at depth.

Joint orientation in the Waterways is thought to be independent of lithologic character or stratigraphy. Jointing is a consequence of tensile overstressing due to regional uplift and thus the predominant sets are parallel and perpendicular to the strike direction of the uplift. Babcock (1975) identified a poorly defined NE-SW/NW-SE secondary system, however Williams (1980) concluded: "there is no certainty that these features represent a joint set". The present author observed only random fractures in addition to the dominant joint sets in local outcrop (Appendix D). These random fractures are believed to be due to stress relief or surface weathering. They are not thought to represent a major structural occurrence and are not considered to comprise a readily identifiable secondary joint system.

Joints of the predominant system are orthogonal and subvertical. They rarely cross two distinct lithologies and are spaced according to the thickness and stiffness of the various lithologic units. Williams (1980) reported the highest joint density of 0.65-4 m in the massive crystalline limestone. Spacings up to several metres were recorded in thicker units.

In summary, the author distinguishes between joint features observed at the surface and those encountered at depth. Surface joints are rough, discontinuous and closely spaced. Buried joints are likely to be less rough, more widely spaced and bitumen-filled. These differences are attributed to the stress relief and weathering of surface outcrop.

5.2.3 Empirical Classification

Among widely accepted empirical rock mass classification systems are those proposed by Terzaghi (1946), Deere (1964), Lauffer (1958), Wickham, Tiedemann and Skinner (1972), Bieniawski (1974, 1976) and Barton, Lien and Lunde (1974). Two of these systems have been selected to assess the Waterways Formation. Detailed information on the CSIR Rock Mass Rating (RMR) system and the Norwegian Geotechnical Institute (NGI) Q system can be obtained from Bieniawski (1974, 1976) and Barton et al. (1974) respectively. Although both of these systems have limitations, they are believed to be the most modern and comprehensive classifications available.

Both systems rely heavily upon an accurate assessment of geological structure and require a significant amount of qualitative judgement. Neither system accounts for excavation shape or the localized disturbance caused by construction blasting. Although both systems incorporate groundwater inflow terms, neither accounts for hydraulic head or pore pressure. Inflow volumes per unit length are employed and do not represent a measure of hydraulic pressure. The NGI-Q system is however, more sensitive to groundwater inflow than the CSIR-RMR.

The CSIR-RMR parameter is not directly sensitive to stress conditions, however both rock mass strength and the groundwater inflow terms are stress level dependent. Discontinuity infillings and roughness may be affected at high stress levels, however neither is a direct measure of a change in the stress field. The RMR is also insensitive to excavation dimension.

Th NGI-Q parameter is directly sensitive to stress conditions via the stress reduction factor (SRF). Similarly, the joint set number, joint alteration and roughness numbers and water reduction factor may all be indirectly affected by stress level.

In summary, the CSIR-RMR system emphasizes structural considerations and orientation. It does not account for stress state, excavation dimension or shape. The NGI-Q system does account for the stress field, but neglects joint orientation. Both systems adequately assess discontinuity properties but neither accounts for pore fluid pressures.

Figure 5.2 summarizes the classifications completed for five Waterways lithologies. It is recognized that rock quality (RQD) parameters recorded during the core study may be unrepresentative. High fracture densities were characteristic and thought to be partially due to drilling and handling procedures. Moreover, vertical discontinuities could not be assessed from vertically oriented core. The author therefore estimated RQD values to be employed in the empirical classifications. Groundwater effects and stress conditions were also estimated. Favourable joint orientations were assumed for calculation purposes and all joint roughness, spacing and alteration data were derived from core or outcrop observations. Both the most undesirable and most desirable conditions were assumed for each lithology to provide realistic upper and lower bounds to rock mass quality. A review of Figure 5.2 reveals the following general observations.

Firstly, the CSIR RMR-system consistently rated all rock types slightly higher in quality than the NGI

Lithology	RQD[1] (%)	Deere (1964)	NGI Q - System						CSIR RMR-System					Rock Mass Rating		
			J_n	J_r	J_a	J_w	SRF	Q	σ_c[2]	Spacing	Condition	G/Water	RQD	Corrected	Q	RMR
Massive Crystalline Limestone	80 (min)	good	4	1.5	2.0	0.33	5.	0.99	7	20	20	4	17	66	v. poor	II (good)
	95 (max)	excellent	4	2.0	0.75	0.7	2.5	17.73	10	28	25	8	20	89	good	I (v.good)
Nodular (Marbly) Argillaceous Limestone	60 (min)	fair	6	1.5	2.5	0.33	5.0	0.40	4	20	20	4	13	49	v. poor	III (fair)
	85 (max)	good	6	3.0	1.0	0.66	2.5	11.22	7	[illegible]	25	8	17	80	good	II (good)
Finely Interbedded Micrite and Limestone	40 (min)	poor	6	1.5	2.5	0.33	5.0	0.28	4	20	15	4	8	40	v. poor	III (fair)
	75 (max)	fair	6	3.0	1.0	0.66	2.5	9.90	7	25	25	8	13	66	fair	II (good)
Calcareous Marine Shale	40 (min)	poor	6	1.0	2.0	0.33	50.0	0.23	4	15	12	4	8	31	v. poor	IV (poor)
	75 (max)	fair	6	1.5	1.0	0.66	2.5	4.95	7	25	20	8	13	71	poor	II (good)
Biohermal Limestone	50 (min)	poor	5	1.5	2.0	0.33	5.0	0.53	6	20	20	4	10	58	v. poor	III (fair)
	80 (max)	good	5	3.0	1.0	0.66	2.5	12.67	10	25	25	8	16	72	good	II (good)

NOTES: (1) Minimum and maximum rqd values represent the worst and best rock conditions envisaged for each lithology.

(2) Uniaxial compressive strengths were derived from Williams (1980)

(3) Corrected RMR values are less two to account for the assumed favourable joint orientation.

Figure 5.2: Empirical Rock Mass Classifications

Q-system. Although both systems rate the various lithologies from very poor to good, the RMR rock quality classes range only from poor to good. Clearly, the Q-system is very sensitive to the stress reduction factor (SRF) which attempts to account for the state of stress and tunnelling conditions. All "very poor" ratings were obtained by employing high SRF factors appropriate for heavily jointed rock. More modest SRF values yield higher Q values and thus more favourable quality classifications.

Secondly, both systems emphasize the reduction in rock mass quality associated with higher fracture densities. Fracture characteristics and orientation exercise less influence than the spacing of joints because spacings are actually incorporated twice by virtue of RQD values. As previously discussed, the SRF factors and thus Q, are highly sensitive to joint density. Groundwater factors are also influenced by joint spacings.

Thirdly, neither system is capable of accounting for random solution features or sinkholes. Such structures represent disturbed materials that may exhibit post-peak strength behaviour or local instability. Neither the Q nor RMR system accounts for such random occurrences. Both are ineffective in providing appropriate design recommendations. The occurrence of collapse breccias underground should be avoided by employing detailed site investigations, however if such conditions are encountered unexpectantly, the construction program must have the flexibility to undertake additional support or stabilization requirements.

In summary, both the CSIR and NGI rock mass classifications affix poor to good quality ratings on the Christina and Moberly Members. The ratings were based upon the author's interpretation of in-situ conditions and may be updated as further data is acquired from underground excavations. Neither system adequately accounts for regional solution or erosional features, but both display the overall sensitivity of rock quality rating to joint fracture density. The CSIR-RMR system provides a more favourable rating for all lithologies but does not account for stress conditions as in the NGI stress reduction factor. The selection of SRF is largely subjective and requires considerable engineering experience. Support recommendations were not compared.

5.2.4 Empirical Failure Criterion

Hoek and Brown (1980) recently proposed an empirical failure criterion for rock that relates the principal stresses at failure by the following equation:

$$\sigma_1 = \sigma_3 + \sqrt{m\sigma_C\sigma_3 + S\sigma_C^2}$$

where σ_1 = major principal stress

σ_3 = minor principal stress

σ_C = uniaxial compressive strength of the intact rock

m,s = empirical constants which depend upon the rock properties and degree of breakage

The parameters m and s are dimensionless strength parameters. m varies with rock type, the angle of interparticle friction and the degree of particle interlocking within the rock mass. m decreases as the degree of prior fracturing increases and is generally obtained by curve-fitting triaxial test data. The s parameter depends on the interparticle tensile strength and the degree of particle interlocking. For intact rock, s=1 and m is given by Equation 5.1.

$$m = \frac{1}{\sigma_C} \; \frac{\Sigma x_i y_i - \dfrac{\Sigma x_i \; \Sigma y_i}{n}}{\Sigma x_i^2 - \dfrac{(\Sigma x_i)^2}{n}} \qquad (5.1)$$

where σ_C = uxiaxial compressive strength

x_i, y_i = successive triaxial test data pairs

n = number of $(x_i,\ y_i)$ data pairs

For broken or heavily jointed rock, m may be determined as in Equation 5.1 and the S parameter is given by Equation 5.2.

$$S = \frac{1}{\sigma_C^2} \left[\frac{\Sigma y_i}{n} - m\sigma_C \frac{\Sigma x_i}{n} \right] \qquad (5.2)$$

For highly broken or brecciated rock, S may be assumed to be zero.

The normal and shear stresses acting on a plane inclined at β degrees to the major principal stress direction may also be expressed in terms of the principal stresses.

$$\tau = \tfrac{1}{2}(\sigma_1 - \sigma_3) \sin 2\beta \qquad (5.3)$$

$$\sigma_n = \tfrac{1}{2}(\sigma_1 + \sigma_3) - \tfrac{1}{2}(\sigma_1 - \sigma_3) \cos 2\beta \qquad (5.4)$$

In general, this criterion is applicable only in the "brittle zone" as defined by Mogi (1972) where $\sigma_1 > 4.1\ \sigma_3$ (Figure 5.3). Within this zone, a Mohr envelope may be empirically determined that governs the expected rock mass behaviour (Figure 5.4). As expected, these rock mass envelopes are smaller than those prepared by Williams

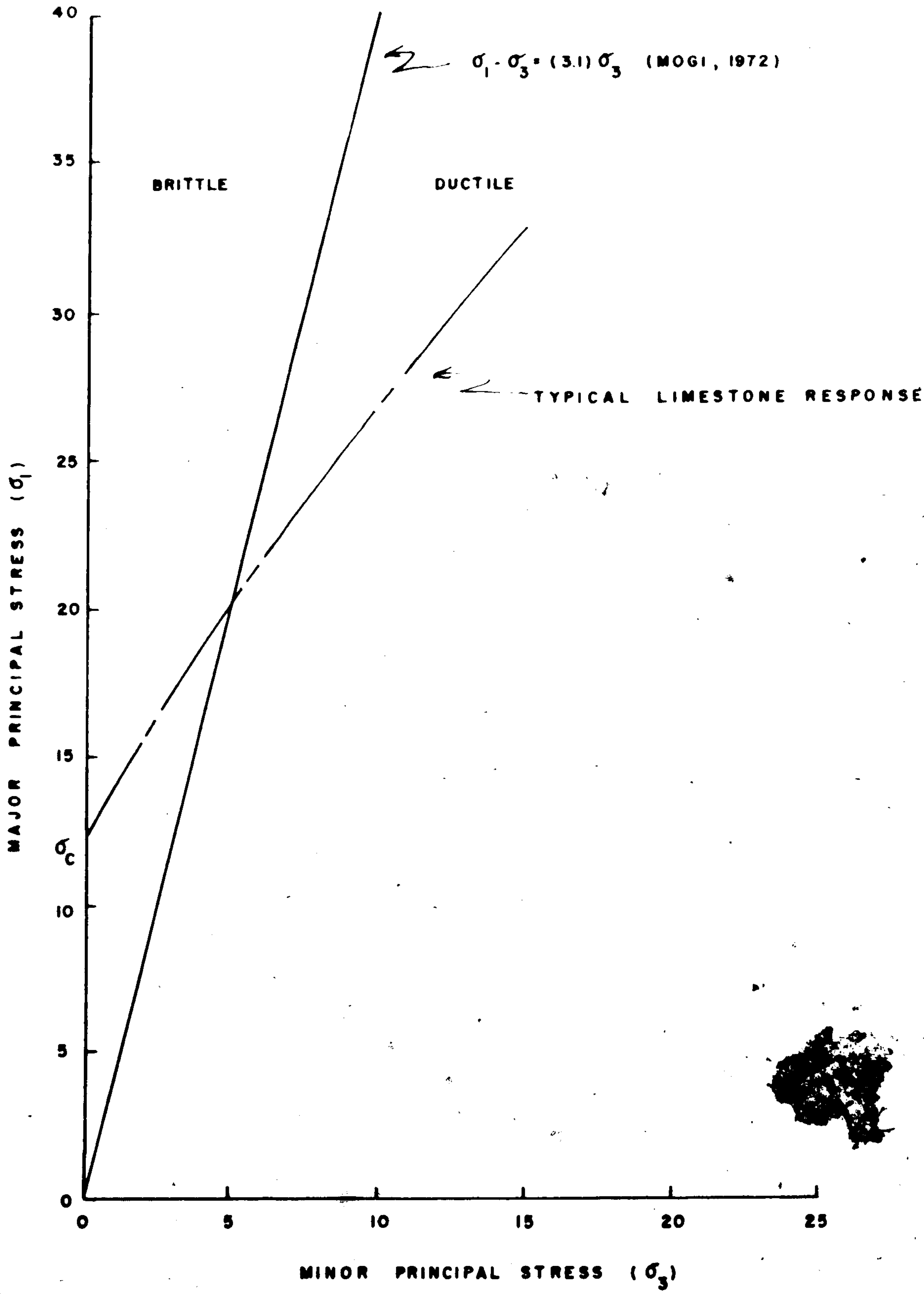


FIGURE 5.3: BRITTLE - DUCTILE TRANSITION (after Mogi,1972)

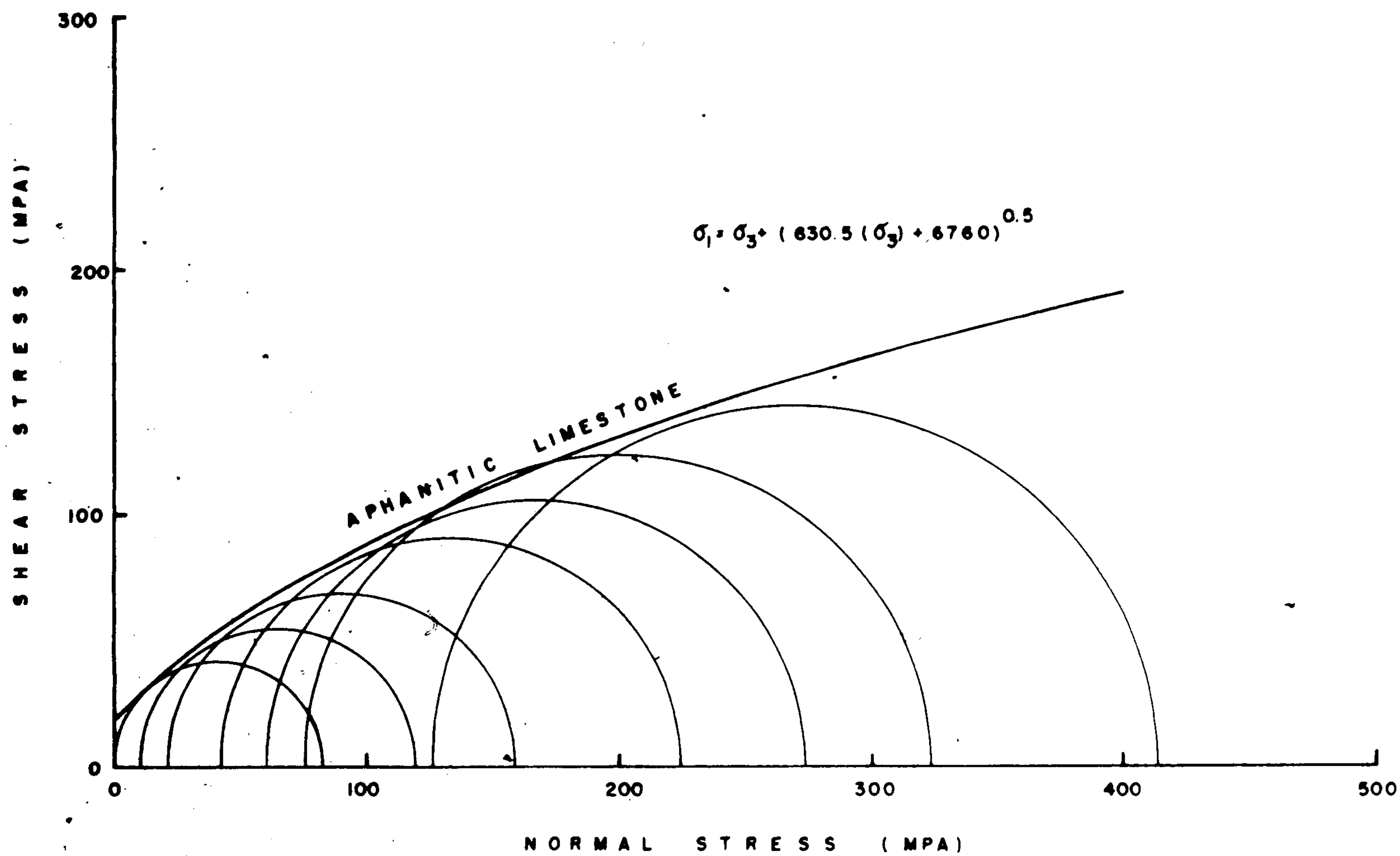


FIGURE 5.4: ROCK MASS FAILURE ENVELOPE DERIVED EMPIRICALLY FROM HOEK AND BROWN'S (1980) CRITERIA

(Intact Rock) Triaxial Test Data			(Rock Mass) Empirical Failure Criterion	
σ_1 (Mpa)	$x_i = \sigma_3$ (Mpa)		σ_1 (Mpa)	σ_3 (Mpa)
99.2	3.5	$n = 8$	82.22	0
102.2	7.7	$\Sigma x_i = 111$	115.30	10
115.7	8.8	$\Sigma y_i = 123472.49$	159.18	20
125.5	10.5	$\Sigma x_i^2 = 1971.28$	218.83	40
148.6	14.8	$(\Sigma x_i)^2 = 12321.0$	271.16	60
155.5	17.4	$\Sigma x_i y_i = 1984903.53$	319.17	80
171.1	27.6	σ_c = 130 Mps (intact)	407.1	120
172.9	20.7			
	$\Sigma x_i = 111$			

$\therefore$ M = 4.85, S = 0.40

Hoek & Brown failure criteria (rock mass)

$$\sigma_1 = \sigma_3 + (630.5\ (\sigma_3) + 6760)^{1/2}$$

NOTE: All triaxial data derived from Williams (1980) for saturated aphanitic limestone. σ_1 oriented perpendicular to bedding. All samples loaded at 0.102 mm/min strain rate and all failed at less than 0.5% axial strain

Figure 5.5: Hoek and Brown (1980) Empirical Failure Criteria

(1980) for the intact rock.

The m and s parameters derived in Figure 5.5 are based upon Williams (1980) triaxial test data and are slightly higher than the generalized parameters proposed by Hoek and Brown (1980). This indicates a better quality rock mass than the predicted norm. The calculated parameters also compare favourably with the Q and RMR rock mass classifications as suggested by Hoek and Brown(1980) and prepared in Section 5.2.3.

5.3 Surface Mining Projects

5.3.1 General Concerns

Considerable experience in open pit mining of oilsand has been gained through two decades of commercial production at the SUNCOR and SYNCRUDE sites. As a result, there is a substantial body of knowledge concerning the geotechnical problems associated with mine development. In particular, all major geotechnical problems associated with mine development may be related to one of the following general areas of study:

1. ore body properties and behaviour
2. by-product properties and behaviour
3. hydrogeology
4. mine floor trafficability and general

bearing capacity

5. open pit highwall stability.

Although each of these areas is of great geotechnical concern, clearly only the latter three are influenced by Devonian features or behaviour.

Hydrogeological concerns are concentrated about the presence of an upward hydraulic gradient throughout the Devonian and the existence of pressurized basal McMurray alluvium (Ozoray, Hackbarth and Lytviak, 1980). The alluvium is primarily fine-grained sand and silt and is particularly subject to piping. It is uncemented and will experience a loss of strength upon saturation and unloading. These conditions are unfavourable for both bearing capacity and slope stability scenarios.

In addition to these stability concerns, significant groundwater inflows may be experienced. This condition may be aggravated by unloading due to excavation and the anisotropic permeability of the limestone. Solution pipes and collapse sinkholes are also expected to act as vertical hydraulic conduits. The stability of these structures is discussed in Section 5.3.3. In general mines adjacent to the Athabasca River should be well drained due to the river's local discharging influence.

Mine floor trafficability and bearing capacity are inherently related to hydrogeological concerns, however they also depend largely upon paleotopography and the properties of the basal McMurray sediments. In general, the limestone lithologies provide a secure, competent basement upon which mine floor workings may be conducted. In certain orientations however, the limestone surface is too deeply buried to serve as the mine floor. Under these conditions, the mine floor will be either McMurray sands or unconsolidated Cretaceous alluvium. The latter materials are considered to be weak, uncemented, and deleterious. Mapping of the basal Cretaceous alluvium or bulk removal may be required under extreme conditions. Paleotopographic highs or pinnacles may also be encountered and should be removed as required by blasting.

In summary, open pit mining ventures are relatively insensitive to Devonian structural features. Of greatest potential concern are the dewatering, bearing capacity and slope stability problems generated by Waterways permeability and collapse structures. Grouting may be required to mitigate these problems. Alluvial materials are generally weak and deleterious and may be of concern in certain unfavourable orientations.

5.3.2 Highwall Stability

Dusseault (1977) studied the geotechnical behaviour of Athabasca oilsand in detail and considered the stability of both natural slopes and open pit highwalls. Natural slopes were both high and steep and were characterized by exfoliation ravelling. Their deep-seated stability was primarily attributed to the high natural strength of the oilsand, however stream erosion, bitumen saturation, grain size, bedding, cementation and exposure angle also influenced stability. Potential deep-seated instabilities were thought to be wedge-shaped and influenced by basal McMurray clays. Dusseault (1977) characterized these clays as presheared materials with low residual angles of shearing resistance. The strain incompatability of the clays with adjacent oilsand or limestone was not addressed. The absence of swelling clays was noted.

Dusseault and Morgenstern (1978) summarized Dusseault's (1977) findings and stated that "no significant deep-seated rotational or slump failure of any oilsands slope" had recently occurred. They also stated that the "high strength of limestone and its resistance to erosion result in, steep limestone ledges at the base of slopes". This feature was considered to prevent toe erosion, but no strength or durability indices for the limestone were quoted.

More recently, Brooker and Khan (1980) reviewed the design and performance of oilsand slopes in surface mining projects. They confirmed the occurrence of ravelling failures and identified four primary slope stability concerns:

1. stability of the ore body
2. stability of the overburden Clearwater Formation
3. stability of the ore reclaim pile
4. stability of in-pit overburden and reject pile materials

Deep-seated (Devonian) stability concerns were not identified, however Brooker and Khan (1980) noted the importance of basal McMurray materials. They considered these materials to be granular deposits, predominantly sands with interstratified silts and clays, which were under artesian hydraulic pressure. These aquifers were thought to be stratigraphically discontinuous and not readily depressurized by single well relief measures. Measured shear strengths varied from residual values of 7° to peak values of 23° with mild cohesion.

Finally, Khan, Fair and Cuddy (1982) documented the character of basal stability problems experienced at SYNCRUDE. They noted that in SYNCRUDE'S 1973 trial test pit, significant groundwater inflows were encountered and substantial depressurization was required to complete the excavation. Considerable pit floor heave was experienced after abandonment and attributed to artesian groundwater conditions.

In general, the Devonian limestone was considered to be a "passive hydrogeologic system" characterized by a low permeability. The authors suggested the limestone acted as a hydrogeologic barrier separating basal McMurray deposits from the Lower Devonian and cited the lack of groundwater inflow at SUNCOR to support their contention. They were unable to account for the variable salinity of basal sand groundwaters but suggested that such groundwaters were connate. Pore pressure recovery around the test pit indicated that Devonian recharge was unlikely. Instead, recharge appeared to occur from adjacent outlying basal deposits.

Khan, Fair and Cuddy (1982) also assessed highwall stability mechanics and reported on the nature of basal instabilities at SYNCRUDE. Such instabilities were attributed to the combined effects of low shear strength and high pore pressures in the basal deposits. Stress redistribution due to excavation was also considered to contribute to overstressing of the toe which may be further aggravated by unfavourable strata dipping toward the excavation or too rapid excavation of the mine. Piping, buckling or mine floor heave were considered to be due to excess basal head conditions which could lead to multi-block progressive slope failure. Remedial measures included local aquifer depressurization, slope angle modification and toe berming or buttressing.

These studies collectively suggest that deep-seated Devonian instabilities are of little concern in mine highwall design. In general, the Waterways limestone provides a strong, stable basement which poses no serious stability threat. There are however, certain unfavourable orientations that are considered worthy of further discussion. In particular, placement of the pit highwall subparallel to a major pre-Cretaceous drainage channel is considered an unfavourable orientation (Figure 5.6). Alluvial infillings are weak, deformable materials that are unsuitable in the toe region. Although massive highwall failure may not result, significant heave or buckling may occur in the mine floor.

Failures through intact limestone are considered unlikely events due to the high cohesive strength of the rock. Vertical fractures may however, act as failure planes, particularly if frictional resistance is reduced by high pore fluid pressures. In addition, unloading due to mine advancement results in an overall reduction of confining stresses and thus a reduction of the shearing resistance along joints.

A second unfavourable slope orientation, as suggested by Khan, Fair and Cuddy (1982) is that where paleotopography dips toward the excavation (Figure 5.7).

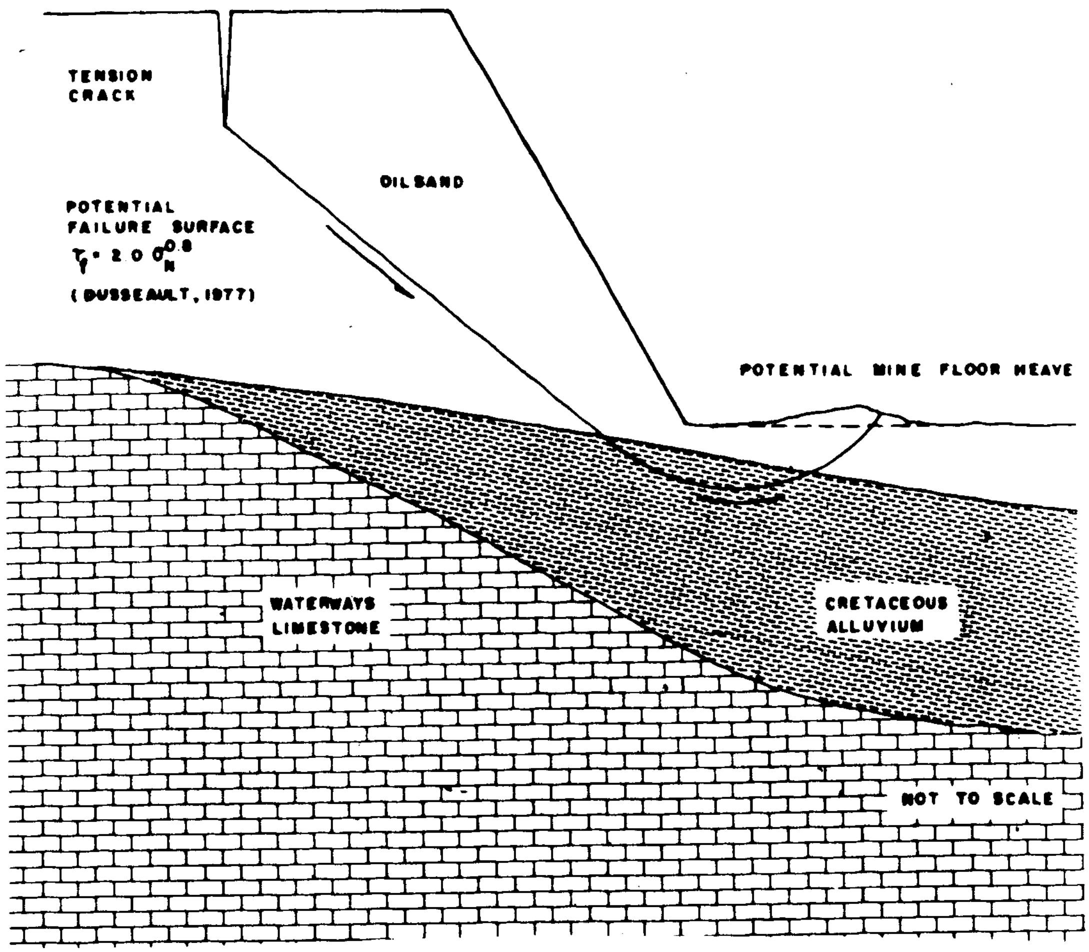


FIGURE 5.6: POTENTIAL HIGHWALL INSTABILITY AND MINE FLOOR HEAVE IN BASAL McMURRAY ALLUVIUM

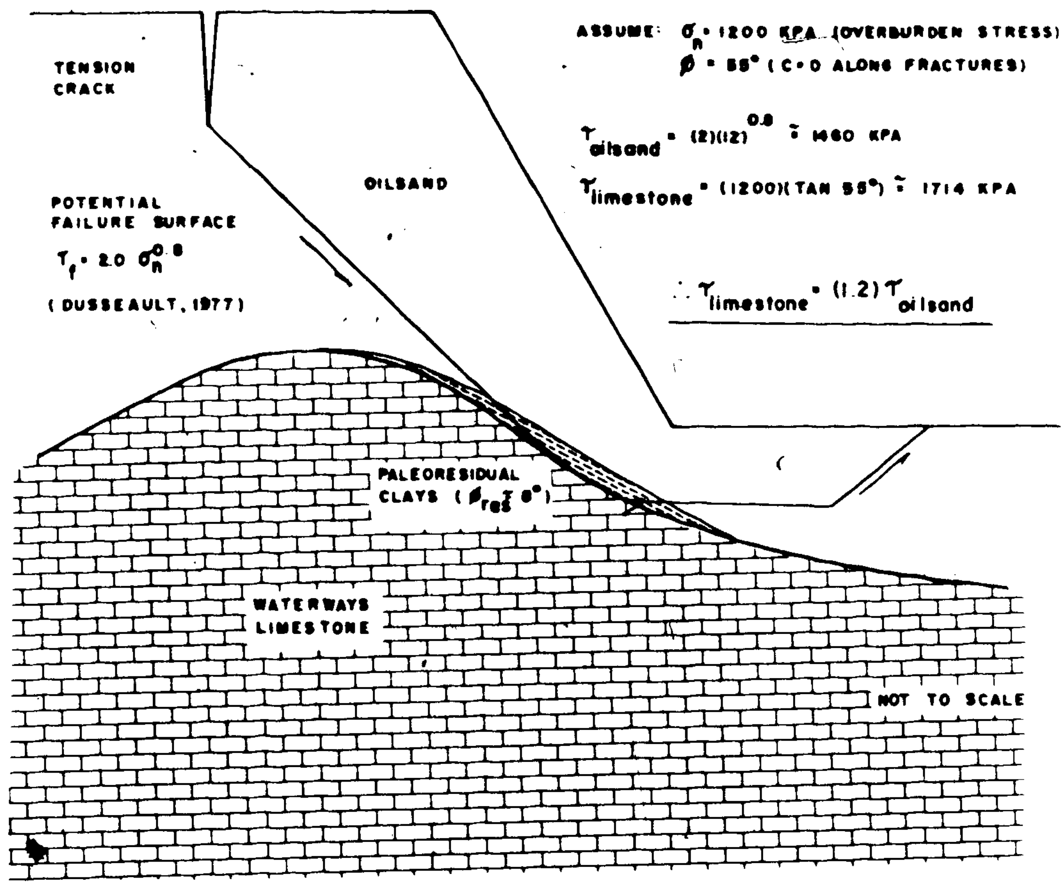


FIGURE 5.7: POTENTIAL HIGHWALL INSTABILITY ON DIPPING DEVONIAN SURFACE WITH WEAK PALEORESIDUAL CLAYS

This condition may be aggravated by paleoresidual clays along the Devonian-Cretaceous contact which may exhibit residual strengths of less than 10°.

It is interesting to note (see Figure 5.7) that at a confining stress of 1200 kpa, the shear strength of a limestone fracture (assuming Mohr-Coulomb criterion) is only 20% greater than that of oilsand at the same confining stress (assuming Dusseault's (1977) power law criterion). Surface weathering, solution and stress relief may serve to decrease this strength further.

In summary, neither natural slopes nor man-made open pit highwalls have, to date, experienced Devonian instability problems. This is generally attributed to the high cohesive and frictional resistance of both the intact rock and its discontinuities. Unfortunately however, the presence of basal Cretaceous alluvium and upper Devonian paleosols creates a considerable instability concern for large wedge-shaped blocks. These materials are unconsolidated and deformable and form an inherent zone of weakness at the toe of many potential oilsand slopes. In some unfavourable orientations, basal block instability may become a serious threat to overall mine servicability or safety. The potential complexity of erosional, solutional and weathering features may serve to compound this threat.

5.3.3 Collapse Structures

The potential for catastrophic ground losses due to solution pipe collapse is of great concern in open-pit mine development. Episodes of unloading and subsequent reloading are a consequence of the mining procedure and are considered to effect changes in the stress field that may jeopardize the stability of known collapse pipes.

In general, collapse pipes are considered to be gravitational slump structures that have translated downward due to a loss of support at the Prairie Evaporite horizon. These collapse episodes are thought to have occurred throughout late Paleozoic and Mesozoic time when overburden stresses may have been greater than at present. If the stability of existing pipes or the creation of new pipes is a primary function of the stress field, then unloading is considered to favour stability. Alternatively, loading such structures may induce further collapse. Despite the influence of stress state upon pipe stability, it is expected that solution of the Prairie Evaporite is the dominant controlling factor. Continued solution is thought to have a greater impact upon overall pipe stability than minor stress field changes. In particular, it is understood that the Prairie Evaporite is not present in several deep wells drilled at the adjacent ALSANDS lease (GCRI, 1981). If this condition also exists below SANDALTA, then local subsidence and collapse may be considered to be complete. Since no further solution or collapse can be accommodated, collapse pipe stability is favoured regardless of changes in the stress field.

In order to assess these potential instabilities, more detailed drilling and a measure of the in-situ state of stress are required. If mapping suggests that collapse pipes occur in unfavourable orientations, grouting may be required to increase their shear resistance prior to excavation.

In summary, although catastrophic ground losses due to collapse reactivation are thought to be unlikely, they should be treated as potential mine instabilities. Stress relief and reloading due to mining may invoke changes in the state of equilibrium of the pipes. Detailed mapping and grouting may be required to mitigate this effect.

5.4 Mine Assisted In-Situ Projects

5.4.1 MAISP Concept

Haston (1978) described the Soviet concept of accessing a hydrocarbon reservoir by drilling thermal stimulation wells from an overlying tunnel. This concept has the particular benefits of efficient steam transmission to the reservoir and a more favourable use of horizontal production wells. Haston (1978) considered the concept to be viable in the Athabasca oilsands at depths between 60 and 250 metres where surface mining methods are not feasible. Stephenson (1978) found the in-situ concept to be more economic than the underground block and cave techniques described by Patching, Jeremic and Stimpson (1978).

Mathews (1980) stated that the MAISP concept involves "thermal stimulation .... where production would be achieved by heat soaking the formation to provide communication between adjacent well holes and then sweeping with a steam drive". Candidate sites would have a recommended depth of cover of 150-220 metres and both injection and production wells would be drilled from subsurface mine workings (Figure 5.8). Several authors (Roesner and Poppen, 1978; Brooker, Devenny and MacRae, 1978) have examined the feasibility of driving the mine workings within the McMurray or overlying Clearwater Formations. Haston (1978) noted however, that mining concerns favour the underlying limestones and that the economy of the MAISP concept is insensitive to the depth of operation. Haston (1978) also outlined some of the problems inherent in a limestone based MAISP project; primarily directional well control and pressurized basal McMurray aquifers. Mossop (1978) also recognized the potential difficulties of mining at the base of the McMurray in light of the complex nature of the Devonian surface. Stephenson

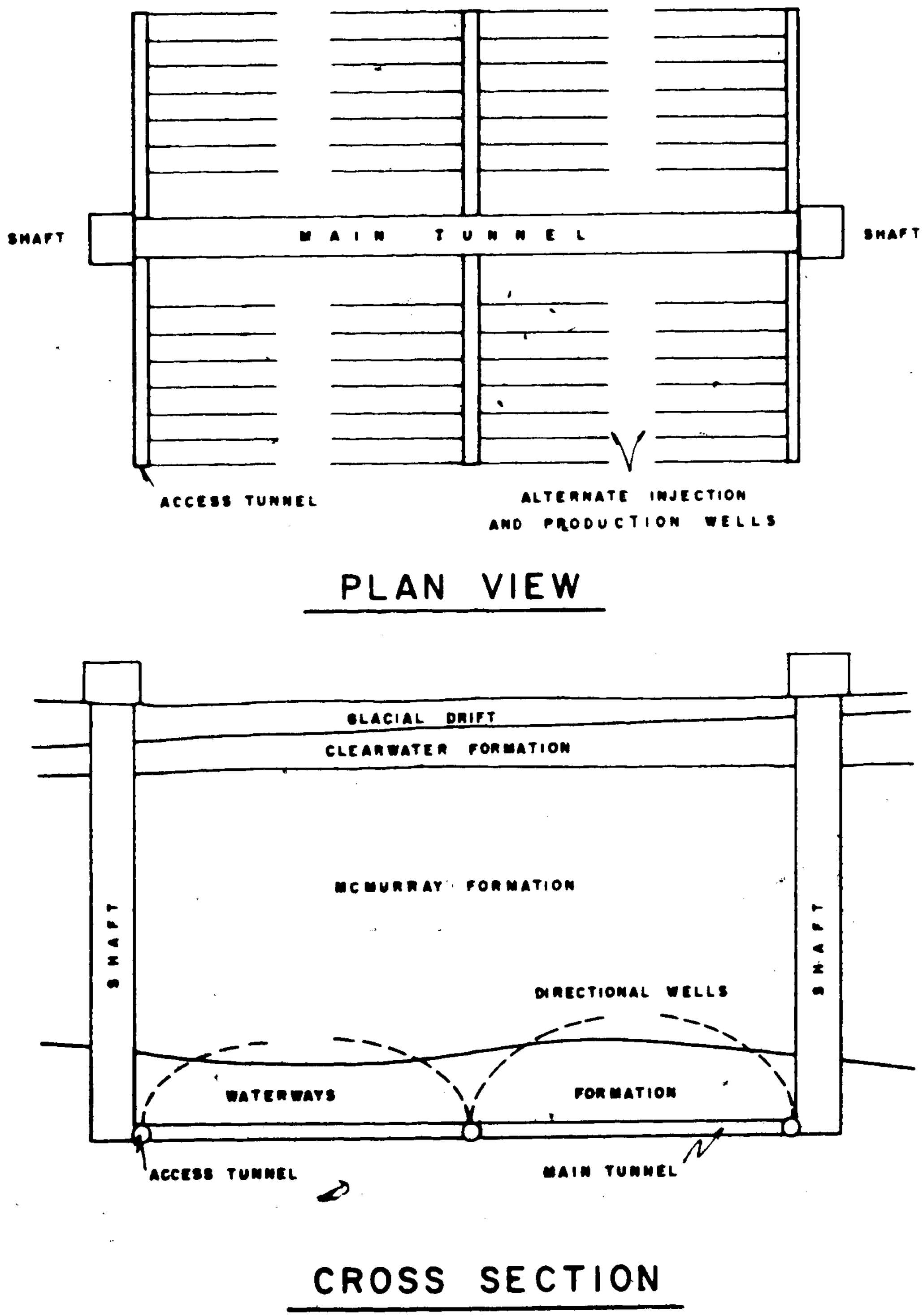


FIGURE 5.8: MINE ASSISTED IN-SITU PRODUCTION (MAISP) CONCEPT

(1978) added that little was known of the limestones and that greater emphasis should be given to determining the areal extent and dimensions of solution features. Mathews (1980) listed the following factors believed to have a major impact upon economic feasibility:

1. steam/oil recovery ratio
2. recovery percentage and rate
3. maximum well density efficiency
4. pay zone thickness

Recent efforts near Mt. McMurray (Figure 1.1) have been directed toward the development of a MAISP pilot in the Waterways Formation. Detailed geological and geotechnical studies have been completed, however underground construction has not commenced. The ultimate commerical viability of the MAISP concept will be judged largely upon experience gained from such pilot projects.

5.4.2 Current In-Situ State of Stress

Various authors have considered the presence of high horizontal stresses within the McMurray Formation. In particular, recent publications by Brooker (1975), Dusseault (1977), Settari and Raisbeck (1978) and Holzhausen, Wood, Raisbeck and Card (1980) have dealt with this issue. Few studies have however completed an evaluation of the virgin stress state within the Waterways. Williams (1980) expected the principal stresses to be oriented vertically and horizontally, but made no in-situ measurements of the stress tensor. He equated the vertical principal stress with the overburden stress and estimated horizontal stresses would be 43% to 67% of the vertical stress (K_o = 0.43-0.67). Although Williams (1980) recognized the potential for high horizontal stresses, he discounted K_o values in excess of unity by citing time relaxation, dissipation and the lack of circumstantial evidence such as heaving in the SUNCOR pit floor. Overburden removal, glacial loading and Laramide tectonic compression were recognized as potential sources of high horizontal stresses.

Other regional studies throughout Western Canada and the northern United States have revealed high horizontal stresses in shallow rock formations. Franklin and Hungr (1978) stated that throughout much of Central Canada, horizontal stresses in the 5-15 mpa range commonly exist at depths up to 100 metres. Such stresses commonly exceed overburden stresses and are typically aligned northeasterly to easterly.

McGarr and Gay (1978) concurred with this finding and emphasized the ubiquity of high horizontal stresses at shallow depths. They added that the effects of gravity, uplift, erosion or temperature change are all unlikely sources of this stress condition.

More recently, Bell and Gough (1979) and Gough and Bell (1981) have examined oil well breakouts throughout Central and Southern Alberta. They noted that well breakouts tended to elongate boreholes in the northwest-southeast direction and attributed this to a northeast-southwest major principal stress. Gough and Bell (1981) emphasized that this orientation is consistent throughout much of the Western Canadian sedimentary basin. They also favoured a strike-slip compressional stress field (σ_1 = NE-SW, σ_2 = vertical, σ_3 = NW-SE) over a thrust stress field (σ_1 = NE-SW, σ_2 = NW-SE, σ_3 = vertical). A normal fault stress field (σ_1 = vertical) was considered unlikely. Additional support for the proposed orientation was provided by steam injection wells at the nearby Cold Lake Project. Residual stress due to Laramide orogenic compression and traction of the North American crustal plate were quoted as the most likely sources of horizontal stress.

During the present study, many unique core features were observed that provide indirect information about the in-situ state of stress. Although none of these features are individually conclusive, collectively they provide considerable circumstantial evidence to support modest K_o values.

The development of boudinage provides no information on the current state of stress, however it does confirm the existence of a vertical major principal stress up to and including the time of lithification. This is compatible with the expected state of stress in unconsolidated marine floor sediments where the total vertical stress is coincident with the overburden stress. A greater consequence of boudinage formation is the development of significant formation porosity and vertical permeability. This permeability may later have been supplemented by vertical formation joints, but suggests that at the time of bitumen infiltration, the major principal stress was not likely horizontal. In order for infiltration to occur, vertical fractures must have been open. High horizontal stresses would have discouraged this opening in at least one orientation (Figure 5.9). This holds no implication for fractures that may have been opened parallel to σ_1. One may therefore expect to find preferential infiltration of joints that were in this orientation. No core evidence of this feature was identified, however oriented core was not available. The present existence of vertical formation permeability is supported by the upward migration of saline groundwaters as reported by Ozoray, Hackbarth and Lytviak (1980).

The nature of joints themselves provide circumstantial stress state evidence. Such fractures are subvertical tension features which are thought to have formed during a period of regional uplift. Their tensile character suggests an absence of horizontal compression upon creation. Moreover, there is a total lack of either stylolite or slickenside structures.

Stylolites are recrystallized calcite "sutures" found in limestone as a result of pressure solution. They are thought to result from rock mass compression, however no displacement is involved. Slickensides are fracture face striae that result from shear displacement along formation joints. They also represent former compressional episodes. Although the lack of these features does not preclude high lateral stresses, their absence is suggestive of a subdued stress field.

Warping also provides indirect stress state information. Although it has little implication for the current state of stress, it is important to recognize that if present stresses are to be considered residual stresses, there is a noticeable lack of preceding fold structures. Undoubtedly, if previous horizontal stresses had been of sufficient magnitude to induce plastic deformation, one mayexpect to observe convential strike-oriented folds subparallel to the proposed σ_3 direction. Instead, the Waterways is characterized by non-oriented basins and intervening highs which are attributed to regional solution subsidence and warping. No evidence of regional compressional folding was found in either outcrop or core. Again, this does not preclude high horizontal stresses, but suggests they were of insufficient magnitude to affect

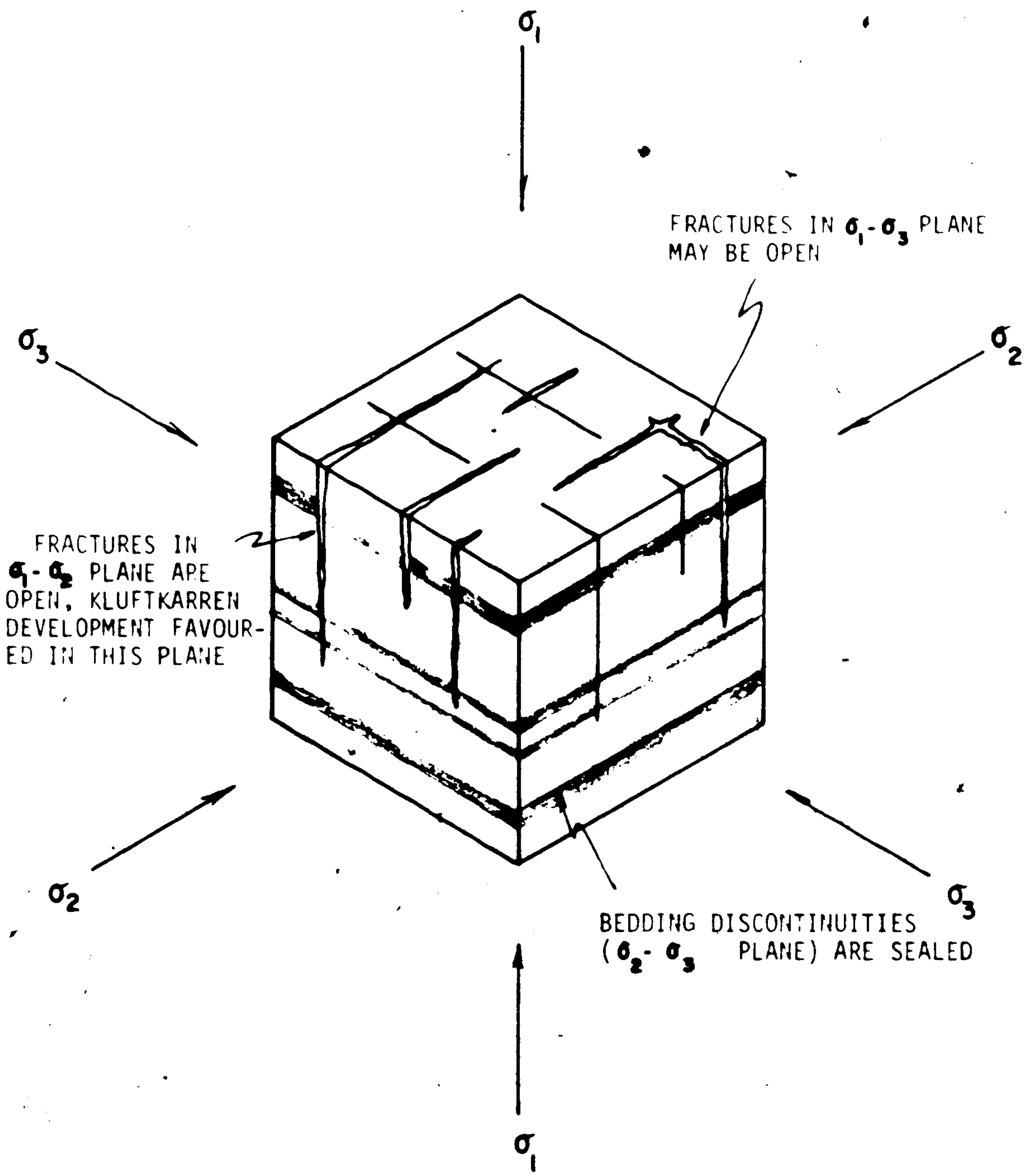


FIGURE 5.9: EFFECT OF REGIONAL STRESS STATE UPON FRACTURE OPENING AND THE DEVEOPMENT, OF KLUFTKARREN

regional folding.

Other less obvious indicators of stress conditions include core squeezing and collapse structures. The lack of plastic deformation or squeezing of soft, deformable clays again discounts high lateral stresses. These materials are expected to possess low deformation moduli, thereby inducing stress transfer. Plastic deformation would occur at low stress levels and was only observed in relation to slumping features.

Collapse structures such as those observed in boreholes 104 and 88 (Plate 4.5) are interpreted to represent slumped materia . that have settled under gravitational forces. If high horizontal stresses had existed at the time of collapse, stress arching is expected to have prevented the upward translation of a collapse pipe. This is incompatible with the observed failure mode. Again, these features hold no implication for the present state of stress. They do discount the probability of high horizontal stresses at the time of collapse.

Finally, although core disking fractures were difficult to discern from dessication and handling fractures, the presence of a high degree of subhorizontal fracturing may support high confining stresses. Obert and Stephenson (1965) reported that disking only occurs at high stress levels where:

$$\sigma_r > 3400 + 2\ So + 0.7\ \sigma_2$$

where

σ_r = radial field stress (psi)

σ_2 = axial field stress (psi)

So = inherent shear strength (psi)

This would suggest that the in-situ stresses at SANDALTA are insufficient to effect a high degree of core disking.

It is noted that the regional faulting proposed by Hackbarth (1978) was that of a normal fault striking northerly with a western downthrown block. Such faulting would be incompatible with the proposed northeast major principal stress orientation of Gough and Bell (1981). Moreover, normal faulting is not the expected mode of failure in a thrust (σ_2 = vertical) or strike-slip (σ_3 = vertical) stress field.

In summary, there are presently no direct core or in-situ measurements upon which an accurate assessment of Devonian field stresses may be completed. There is however, circumstantial evidence to suggest that extreme horizontal loads have never affected the Waterways. The strongest evidence is in the form of an apparent vertical permeability anisotropy, lack of stylolites or slickensides and vertical collapse structures. Secondary support is provided by the formations' warping character and lack of plastic deformations.

Although high horizontal stresses have been identified in the McMurray Formation, they do not necessarily persist at depth. In the SANDALTA locale, Waterways K_O values are expected to be modest; in the range 0.70-1.30. A strike-slip stress field (σ_1 = NE-SW, σ_2 = vertical, σ_3 = NW-SE) or normal stress field (σ_1 = vertical) is favoured. A thrust stress field (σ_3 = vertical) is considered unlikely.

5.4.3 Inhomogeneity in the Stress Field

Although there is little expectation of excessively high horizontal stresses, considerable stress inhomogeneity is envisaged to characterize the Waterways. In particular, complex paleotopography, extended periods of uplift and regional solution subsidence are all thought to have contributed to local stress redistributions. Valley formation, gypsum-anhydrite transformations and local differences in elastic moduli are also considered to have had a limited effect upon the stress field. Although these inhomogeneities may be obscure in light of the stress redistributions expected upon thermal stimulation, they may be of some consequence to construction proceedings.

Paleotopography is likely to exercise the greatest influence upon local stress conditions. Significant stress concentrations may exist in topographic lows causing a reduction in hydraulic conductivity and a local elevation of the shear strength. Overstressing may occur in some underground openings, however the magnitude of these local stress concentrations is not considered to be critical. Alternatively, paleotopographic highs may be stress relieved, exhibiting open fractures and a lower shearing resistance. The depth of influence of these inhomogeneities is a function of the maximum topographic relief. All MAISP tunnels should be located beneath the zone of influence, however access shafts will intersect this zone. Shaft deformations or spalling may result from such local stress concentrations.

Periods of uplift and stress relief are also considered to have affected stress redistribution. Although these represent ancient occurrences, they are believed to have contributed to increased inhomogeneity in the current stress field. Jointing due to tensile overstressing is the obvious manifestation of regional uplift. Another source of potential stress inhomogeneity is the unloading induced by removal of late Paleozoic and early Mesozoic sediments. This unloading may have initiated rebound strains and stress redistributions.

Regional subsidence and local collapse are also thought to have had a considerable influence upon stress redistribution. Prairie Evaporite solution is considered to have led to mild regional settlement which may have induced lateral compressional stresses. Alternatively, local collapse pipes are likely stress-relieved.

Secondary stress field inhomógeneities include valley formation and erosion, gypsum-anydrite transformations and local rock stiffness variations. Proximity to a stress relieved boundary such as the Athabasca River valley, may also affect local inhomogeneity.

In summary, a high degree of stress inhomogeneity may be expected throughout the shallow Waterways members. This inhomogeneity is expected to decrease with depth as paleotopographic and uplift influences become more subdued. In general, vertical stresses are expected to coincide with the overburden stress, whereas lateral stresses are likely to be anisotropic. These stress inhomogeneities are expected to be significnt at a local scale only. Regional field stresses are thought to be widely homogeneous.

5.4.4 Design and Construction Considerations

5.4.4.1 Paleotopographical Effects

The general characteristics of the Devonian surface are well described by Martin and Jamin (1963), Ozoray (1977) and Mossop (1978). This study adds the following observations based upon a review of stratigraphic cross-sections and Devonian structural maps (see Appendix B and Figure 5.10):

1. A minimum of 100 metres of Devonian relief exists in the SANDALTA locale. Up to 90 metres is due to early Cretaceous fluvial channelling. Surface karstification and local solution subsidence are considered to have played a secondary role.
2. Fluviokarst features are generally immature and are limited to the development of small diameter (5-20 cm) pipes and large, lenticular (0-10 m) cavit·s. All pipes and cavities are infilled with Cretaceous bituminous sands or residual Paleozoic clays. Caverns do not appear to characterize the solution, however kluftkarren may be well developed along formation joints.
3. Surface depressions and fluvial channels are commonly infilled with early Cretaceous unsorted alluvium. Sands and organic silts are common; clays and gravels less common. Paleosols are generally poorly developed, but do form a thin mantle of light green, highly plastic clay immediately atop the limestone. The clays also commonly infill small solution pipes and fractures.
4. Large, round collapse pipes (<400 m diameter)

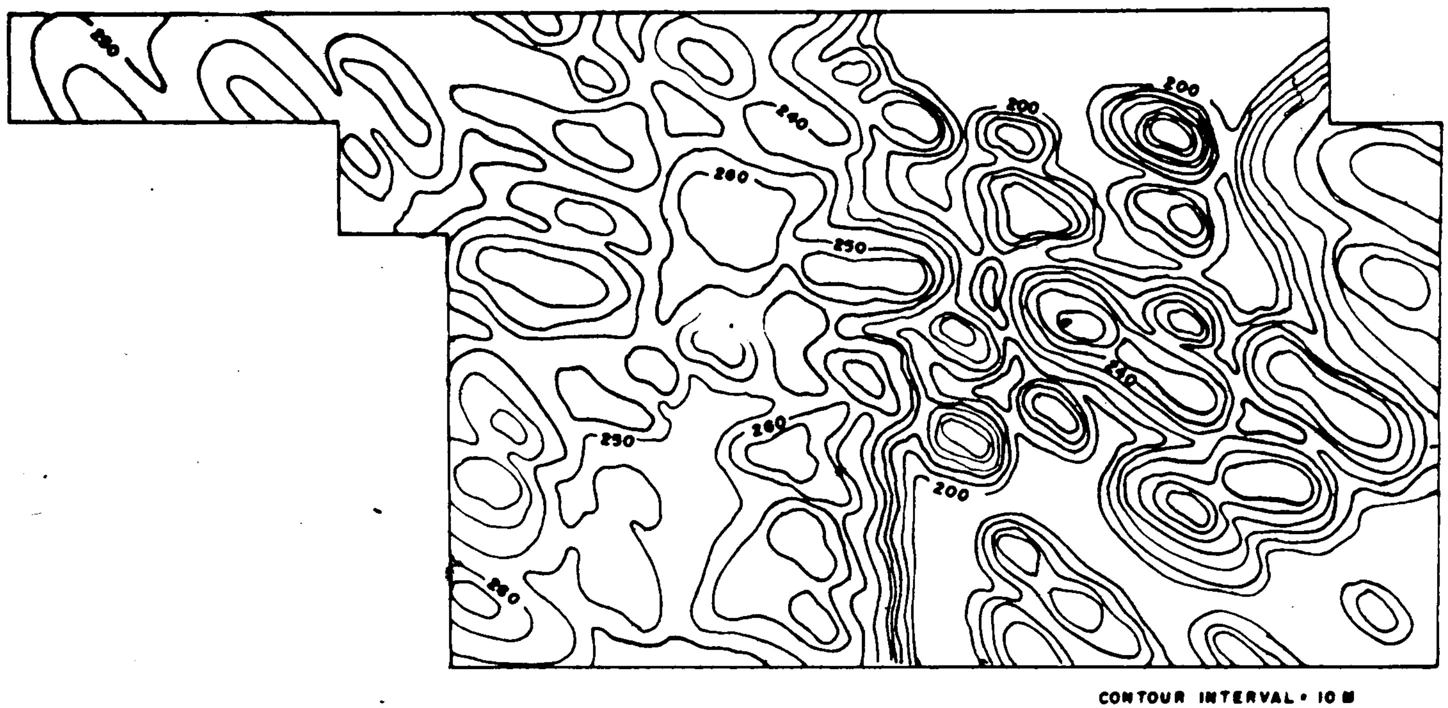


FIGURE 5.10: LOCAL PALEOZOIC SRUCTURE

are sporadically located and are thought to represent the manifestation of Prairie Evaporite solution. They may contribute up to 20 metres of relief.

5. Paleodrainage at SANDALTA was northerly. The predominant orientation of early Cretaceous drainage channels is locally north-south.

6. Regional surface dip is insignificant relative to the local effects of erosion, subsidence and solution.

These paleotopographical features, if present in the mine assisted in-situ area, will exercise a considerable influence upon MAISP construction. In particular, underground workings should avoid intersecting a north-south fluvial channel that may be infilled with unconsolidated alluvium. These materials are considered weak and deleterious. They are subject to hydraulic piping and are not suitable in the buffer zone because of their uncemented permeable character. Clearly, the delineation of early Cretaceous drainage channels is a priority in MAISP site investigations. Access tunnels may have to be located deeper in order to maintain the required buffer zone in limestone.

It is noted that preliminary contour mapping at a scale similar to that of Figure 5.10 may mask certain fluvial channels. Narrow channels in particular may be overlooked when contour control is poor. The great complexity of the Devonian surface becomes increasingly evident as greater control is established. Figure 5.10 reflects first order paleotopography and does not clearly distinguish the fluvial channels observed in Sections A-A' to C-C' of Appendix B.

Subsurface workings should also avoid known collapse pipes. Such features are disturbed, weakened structures that may be metastable. Stress redistribution may affect substantial ground losses or collapse in underground workings. Grouting or rock bolting may serve to stabilize such features.

Smaller scale solution features such as karren or dolines may also be encountered, however they are not expected to jeopardize overall mine integrity. Both intraformational unconformities and steep angle shear zones should be considered inherent zones of weakness. Their presence may induce preferred block instabilities during tunnelling. Such surfaces should be delineated during pre-construction site investigations.

Finally, as discussed in Section 5.4.3, local paleotopography may exercise significant control upon shallow stress inhomogeneity. Stress concentrations are expected to dissipate with depth.

To conclude, paleotopographical effects are not expected to influence MAISP development much beyond the construction stage. During construction however, erosional and solution features may be encountered. Such ground conditions warrant detailed pre-construction site investigations.

5.4.4.2 Hydrogeological Effects

The viability of a MAISP project will be largely dependent upon the control exercised over steam injection, fracture propagation and bitumen recovery. All of these factors depend upon the assumption that the limestone will provide a strong, impermeable hydrogeologic basement. Section 3.6 revealed the potential for substantial vertical permeability. It was suggested that Waterways permeability was structurally controlled by subvertical fractures which in turn, contributed to a strong permeability anisotropy. Both the rock mass permeability and the degree of anisotropy were considered to be stress level dependent.

Ozoray, Hackbarth and Lytviak (1980) described the occurrence of numerous saline springs, which not only confirmed the presence of vertical permeability, but also supported an upward hydraulic gradient throughout the Waterways. This is believed to be responsible for the presence of pressurized basal McMurray sands. Brooker, Devenny and MacRae (1978) discussed the potential problems of depressurizing these aquifers. Some in-situ permeability measurements have been completed and report values of 10^{-7} to 10^{-10} cm/sec at depths of 340-425 metres (GCRI, 1981).

Although these values are very low, they were obtained from standard borehole tests completed in vertical boreholes. In order to accurately assess Waterways permeability, oriented borehole tests must be adopted. Vertical permeabilty anisotropies cannot be evaluated in vertically oriented boreholes. The potential consequences of ungrouted vertical permeability include significant injection and production losses, groundwater inflow and the possibility of wellhead stability problems.

Grouting is considered to be the most efficient method of eliminating undesirable permeability, however this must be accomplished at pressures that do not exceed in-situ stresses. Secondary grouting may be required if drill and blast methods are employed in tunnel construction.

The long term effects of elevated temperature and pressure may affect both a reduction and increase in formation permeabililty. Elevated temperatures induce thermal expansion which results in a net decrease in permeabilty. Alternatively however, fluid injection will reduce normal effective stresses and favour fracture preservation. Local collapse pipes and shear zones may also serve as hydraulic conduits. Again, grouting may be required to mitigate this effect.

The potential for accelerated fracture corrosion is another hydrogeological effect of concern to MAISP designers. Elevated temperatures and pressures catalyze the solution reaction which may contribute to an overall permeability increase with time. Unfortunately, the degree to which corrosion may be accelerated has not been studied to date. Although these concerns are not considered a major threat to mine integrity, there is considerable need for further investigation of this phenomenon. It is expected the corrosion process may be controlled by influencing injection fluid chemistry.

Another concern related to wetting of the argillaceous lithologies is that of the potential for up to 9% axial swell as measured by Williams (1980) in unconfined laboratory samples. Although small confinement pressures were recorded, 9% axial expa ion is a significant amount of swell and must be considered in tunnel and shaft design. This swell is believed to be due to the rehydration of the clay component in the calcareous shales, however it is emphasized that no smectitic clay species were detected in x-ray diffraction tests.

Oxidation of the sulphate marcasite also results in substantial volumetric expansion. Under certain circumstances, this may result in point loading of a tunnel or shaft lining.

One final concern related to hydrogeology is that of groundwater quality and the potential environmental problems associated with the disposal of saline groundwaters. The treatment or storage of such contaminants may be required in extreme cases. Saline groundwaters may also damage or corrode exposed mine equipment.

5.4.4.3 Temperature and Pressure Effects

The most complex considerations in a Devonian MAISP design are those relating to elevated temperature and pressure regimes. Steam injection will result in stress redistributions and structural deformations that may affect both shaft and tunnel integrity. Three primary effects are considered:

1. earth pressure from an increase in formation volume due to injected steam
2. earth pressure resulting from thermal expansion of .e host limestone at elevated formation temperatures
3. hydraulic pressure resulting from the forced injection of stimulation steam

Charlwood, Byrne, McKinley and Varoglu (1980) treated the thermal-geomechanical aspects of MAISP design in detail. They proposed a retreating mine concept employing a buffer zone around shafts and tunnels into which no direct steam injection would occur. Thus, the greater the buffer zone, the less severe the temperature and pressure effects will be upon structural integrity. These influences must be weighed against the economy of employing shallow mine workings.

At present, the complexity of thermal-geomechanical analyses precludes accurate prediction of either temperature or pressure at tunnel or shaft boundaries. Recent design approaches have involved thermal continuum and crack propagation analyses. The former method generally involves finite element or finite difference modelling of a homogeneous formation material subjected to imposed temperature and pressure gradients. This permits the prediction of simplified conditions at shaft or tunnel linings, however such analyses are highly sensitive to boundary conditions. The second type of analysis generally involves finite element modelling of crack propagation in an elastic medium. This approach does not account for thermal expansivity, however it is useful in modelling fluid flow during the early stages of reservoir stimulation. Undoubtedly, both forms of analysis oversimplify actual formation conditions.

Charlwood et al (1980) discussed the following requirements of a suitable rheological model:

1. ability to model failure mechanisms
2. ability to model rock joints and their strength behaviour
3. ability to model progressive failure and load transfer about mine openings
4. ability to model sustained high temperature effects
5. ability to model thermal failure modes such as spalling and slabbing
6. ability to model time dependent processes

It is unlikely all of these requirements will be satisfied by a singular rheological model. Instead, a combination of conventional rock mechanics methods and idealized numerical models is evolving. The following general statements are presented as an aid in characterizing Waterways thermal-geomechanical behaviour.

1. Volumetric expansion due to fluid injection is expected to be less significant than the influence of thermal expansion and hydraulic pressurization. Volumetric expansion may however, induce significant stress redistribution during the early stages of injection. The influence of all three effects are subdued by increased buffer zone thickness.

2. Elevated formation temperatures may create measurable earth pressures on linings due to thermal expansion of the limestone. The magnitude of these loads will be a function of the permeability of the formation as undrained thermal expansion exceeds that of drained thermal expansion. A high Devonian permeability will drain injection fluids and reduce the active earth pressure exerted due to thermal expansion. In addition, the

magnitude of the earth pressure increases with proximity to the injection sites. A reduced buffer zone will effect higher limestone temperatures and thus greater thermal expansion. Thermal gradients about the tunnel or shaft may also affect non-homogeneous loading of the lining. Other thermal concerns include the effect of elevated temperatures upon lining materials and well casings, and the long term spalling or slabbing failures described by Charlwood et al (1980).

3. High injection pressures may induce mild hydraulic loads upon tunnel and shaft linings however again, this effect is dependent upon rock mass permeability and proximity of the tunnel to the actual injection site. Reduced permeability will affect higher pore pressures, which may, in turn, result in reduced effective confining stresses and an increased active earth pressure. Substantial Devonian permeability will effectively drain the rock mass and prevent excess pore fluid pressures from accumulating. Unfortunately, injection and production losses may also occur if Devonian permeability is excessive.

4. In general, grouting is considered to be the most effective method of reducing Devonian

permeability. Grouting is however, also subject to temperature and pressure effects. Thermal cracking may occur which serves to establish previous hydraulic communication along formation discontinuities. Wellhead instability and injection losses are undesirable consequences of ineffective grouting.

In summary, the temperature and pressure effects of thermal stimulation dominate post-construction geotechnical concerns. Volumetric expansion, hydraulic loading and earth pressure from thermal expansion are all mechanisms that may impose new loads on shaft and tunnel linings. Design models must account for these loads and maintain tunnel servicability, safety and structural integrity. Further study is required to assess the effect of formation permeability upon injection and production losses, drained or undrained thermal expansion and overall thermal-geomechanical behaviour.

6. CLOSURE

6.1 Summary

This study has examined various geological features of the Waterways Formation and considered their impact upon proposed oilsand developments. In particular, a detailed review of Moberly and Christina lithologies was conducted and a facies analysis completed. Many large and small scale geological features were described and categorized according to their solutional, erosional or weathering origins.

Geotechnical considerations involved a review of the overall rock mass qua ty and an evaluation of the expected impact of the observed geological features upon engineering projects. Preliminary design concerns were developed for both open pit and mine assisted in-situ oilsand recovery projects.

6.2 Major Elucidations

This study has elucidated the following major concerns:

1. A high degree of lateral lithologic variability characterizes the Waterways Formation. The variation is most marked in terms of rock texture which has been related to the shallow marine depositional

environment. All carbonate facies are finely interbedded and highly argillaceous. The predominant Moberly and Christina lithologies are nodular to finely interbedded micrite and argillaceous limestone, calcareous shale, biohermal limestone and limestone intraclast breccia. All lithologies remain unaffected by post-depositional diagenetic processes such as regional metasomatism or dolomitization.

2. The structural history of the formation does not include episodes of regional tectonic compression. There is no core evidence of compressional folding, strike or thrust slip faulting. All structural deformations are attributed to subsidence originating from removal of the underlying Prairie Evaporite Formation. Periods of regional uplift are considered responsible for the development of the predominant N-S/E-W tensile joint system.

3. The paleotopography of the upper Devonian surface is characterized by fluviokarst features. Relief is at least 90 metres and is primarily due to early Cretaceous fluvial channelling. Surface karren and dolines are structurally controlled and contribute to less than 10 metres of overall relief. Deep-seated Prairie Evaporite solution is manifested in

steep angle normal faults and large (<400 m diameter) round collapse pipes or sinkholes. These features are not related to surface karstification. Prairie Evaporite subsidence is considered to contribute up to 20 metres of relief and to the wavy, undulating appearance of bedding in outcrop. Other mesoscopic solution features are concentrated about apparent intraformational unconformities. These represent short-lived periods of intra-Devonian exposure and solution.

4. Paleosols are light green, plastic clays that form a thin mantle of residual Devonian material atop the limestone. They are texturally and mineralogically distinct from the early Cretaceous basal McMurray alluvium which is commonly dark-coloured, unsorted carbonaceous sand, gravel and clay. The early Cretaceous alluvium is quantitatively more abundant than the paleoresiduals and characteristically infills local topographic lows or fluvial channels. The channels also influence the regional distribution of McMurray sands and thus the location of the thickest ore zones. The absence of widespread paleosols and the predominance of highly scoured limestone surfaces reflects a

relatively poorly developed weathering profile.

5. Formation joints and boudinage fractures create the potential for a vertical formation permeability several orders of magnitude greater than horizontal permeabilities. Such anisotropy remains unmeasured but is supported by the presence of upward flowing saline springs and basal McMurray artesian aquifers (Ozoray, Hackbarth and Lytviak, 1980). An upward regional hydraulic gradient across the Waterways was established by Hackbarth (1978). All permeability is structurally controlled and stress level dependent.

6. Bitumen staining in subvertical formation fractures supports both an anisotropic permeability tensor and a normal local stress field (σ_1 = vertical). Infiltrated bitumen further acts as a solution retardant at shallow depths.

7. Overall rock mass quality is only fair to good and decreases with increasing argillaceous content. Engineering behaviour is dominated by rock mass discontinuities such as joints and bedding. Empirical classifications are ineffective in accounting for local solution or erosional features.

8. A normal (σ_1 = vertical) or strike-slip (σ_2 = vertical) stress field is favoured with the vertical stress coinciding with the overburden stress. In-situ stress measurements are lacking but core evidence suggests modest horizontal stresses exist. K_o values are not expected to exceed 1.3. Considerable stress inhomogeneity is expected within the shallow Moberly and Christina Members. This inhomogeneity is due to paleotopography, uplift, stress relief and varying lithologic stiffnesses.

9. Open pit highwall stability is not generally jeopardized by Devonian lithology or structure. Certain unfavourable orientations may result in mine floor heave, but deep-seated block instability is unlikely. Mine floor integrity and trafficability may be jeopardized by basal Cretaceous alluvium or the presence of unstable collapse pipes or sinkholes. Detailed site investigations or remedial measures such as grouting or pinning may be required to stabilize deep-seated collapse structures.

10. MAISP design may be affected by Devonian structure and behaviour. Construction concerns involve the effect of paleotopography

upon the stress state and potential failure mechanisms. Geological structure will also influence tunnel and shaft construction practice. Post-construction concerns include the influence of hydrogeological and thermal-geomechanical effects upon the stimulation and production process. The potential for significant Waterways permeability may influence design modification in order to mitigate injection or production losses and any threat to tunnel or shaft integrity. Drained or undrained thermal expansion of the host limestone may be accompanied by elevated hydraulic pressures and volumetric expansion of the formation. Grouting may be required to alleviate some of these design concerns.

Temperature and pressure concerns cannot be adequately assessed at present by available numerical or analytical means. The thermal-geomechanical interaction of the underground structure with the rock mass is a complex problem requiring much future study. A realistic rheological model must account for the natural complexity of the host rock mass.

6.3 Areas For Further Study

In general, the lithologic and stratigraphic features of the Waterways Formation have been well researched and documented. There is little need to further characterize these aspects, however there is a considerable lack of knowledge of deep-seated structural occurrences and shallow solution features. Devonian or Precambrian faulting mechanisms remain largely unexplored and Prairie Evaporite solution has been inadequately assessed.

This thesis has illuminated several features of the Devonian-Cretaceous fluviokarst but has also illustrated that more detailed drilling will be required to fully characterize shallow karren and dolines.

An effort was made to correlate such features with specific rock facies, however this approach was not fruitful. It suggested that the spatial distribution of small scale features is most likely a function of rock jointing, local petrographic features and regional hydrogeologic gradients. It is questionable whether detailed mapping of such features will prove meaningful. Moreover, the author considers a better understanding of the mechanics and spatial distribution of large, deep-seated collapse pipes to be of greater immediate concern.

Hydrogeologic conditions also require more detailed study. In particular, the in-situ measurement of rock mass permeability and its anisotropy are critical. The presence of basal McMurray artesian conditions and local flow regimes should be established on a site specific basis.

Further work is also suggested in establishing the current in-situ state of stress and fracture densities. These parameters are necessary design factors for MAISP projects and will be required prior to establishing final design linings for tunnels and shafts. The local state of stress affects rock mass permeability and thus construction inflows and pore fluid pressures. Fracture characteristics will influence both groundwater conditions and potential block instabilities during tunnelling.

Geotechnical index properties are considered to have been adequately assessed by Williams (1980) however the thermal-geomechanical behaviour of the limestone remains undetermined. MAISP projects will induce long term elevated temperatures and pressures which are expected to influence ovrall rock mass behaviour. Current methods of analysis do not include a comprehensive rheological model, but do provide a valuable first approximation to thermal expansion mechanics. Future numerical analyses must account for the inherent geological complexity of the given earth material. The potential for accelerated carbonate dissolution upon injection is another process requiring further study.

REFERENCES

Alberta Oilsands Technology and Research Authority 1980. Fifth Annual Report and Five-Year Review, 67p.

Allan, J.A. 1947. Comments on Hume, G.S. 1947, Transactions of the Canadian Institute of Mining and Metallurgy, Volume 50, pp 330-333.

Alsands Project Group 1978. Environmental Impact Assessment, for Alberta Environment, December 1978, Calgary, 401p.

Asquith, G.A. 1979. Subsurface Carbonate Depositional Models: A Concise Review, Petroleum Publishing Co., Tulsa, Oklahoma, 121p.

Babcock, E.A. 1975. Fracture Phenomena in the Waterways and McMurray Formations, Athabasca Oilsands Region, Northeastern Alberta, Bulletin of Canadian Petroleum Geology, Volume 23, No. 4, pp. 810-826.

Babcock, E.A. and Sheldon, L.G. 1976. Structural Significance of Lineaments Visible on Aerial Photographs of the Athabasca Oilsands Area Near Ft. MacKay, Alberta, Bulletin of Canadian Petroleum Geology, Volume 24, No. 3, pp. 457-470.

Baillie, A.D. 1953. Devonian System of the Williston Basin Area, Bulletin American Association of Petroleum Geologists, Volume 39, No. 5, pp. 575-629.

Barton, N., Lien, R. and Lunde, J. 1974. Engineering Classification of Rock Masses for the Design of Tunnel Support. Rock Mechanics, Volume 6, No. 4, pp. 189-236.

Barton, N. 1976. Recent Experiences with the Q-System of Tunnel Support Design, Proceedings of the Symposium on Exploration for Rock Engineering, A.A. Balkema, Johannesberg, Volume 1, pp. 107-117.

Bassett, H.G. 1952. Correlation of Devonian Sections in Northern Alberta and Northwest Territories, Ph.D. Thesis, Princeton University.

Bell, R. 1884. Report on Part of the Basin of the Athabasca River, Northwest Territory, Geological Survey of Canada Report of Progress, 1882, pp.83-84.

Bell J.S. and Gough, D.I. 1979. Northeast-Southwest Compressive Stress in Alberta: Evidence from Oil Wells, Earth and Planetary Science Letters, Volume 45, pp. 475-482.

Belyea, H.R. 1952. Notes on the Devonian System of the North-Central Plains of Alberta, Geological Survey of Canada, Paper 52-27, 66p.

Belyea, H.R. 1955. Correlations in Devonian of Southern Alberta, Journal of the American Society of Petroleum Geologists, Volume 3, No. 9, pp. 151-156.

Belyea, H.R. and McLaren, D.J. 1957. Devonian Nomenclature, A Discussion, Journal of the Alberta Society of Petroleum Geologists, Volume 5, No. 11, pp. 269-276.

Belyea, H.R. and Norris, A.W. 1962. Middle Devonian and Older Paleozoic Formations of Southern District of MacKenzie, Geological Survey of Canada, Paper 62-15, 82p.

Belyea, H.R., Moyer, G.L., Grey, F.F. and Grayston, L.D. 1964. Committee on Slave Point and Beaverhill Lake Formations in Geological History of Western Canada, Alberta Society of Petroleum Geologists, Part I, Chapter 6, p. 60.

Benthin, H.L. 1973. Conventional Oil Possibilities in the Fort McMurray Area, in Guide to the Athabasca Oilsands Area, Alberta Research Council, Information Series 65, pp. 165-171.

Berner, R.A. 1971. Principles of Chemical Sedimentology, McGraw-Hill Book Co., New York, 240p.

Berry, L.G. and Mason, B. 1959. Mineralogy: Concepts, Descriptions, Determinations, W.H. Freeman and Co., San Francisco, 630p.

Bieniawski, Z.T. 1974. Geomechanics Classification of Rock Masses and its Application in Tunnelling, Proceedings of the Third International Congress on Rock Mechanics, Denver, Colorado, Volume IIA, pp. 27-32.

Bieniawski, Z.T. 1976. Rock Mass Classification in Rock Engineering, Proceedings of the Symposium on Exploration for Rock Engineering, Johannesburg, Volume 1, pp.97-106.

Bieniawski, Z.T. 1979. Tunnel Design by Rock Mass Classifications, Technical Report GL-79-19, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 93p.

Brooker, E.W. 1975. Tarsand Mechanics and Slope Evaluation, Proceedings 10th Canadian Rock Mechanics Symposium, Queen's University, Kingston, Ontario. pp. 409-446.

Brooker, E.W., Devenny, D.W. and MacRae, A.M. 1978. Deep Excavation in Oilsand--Why, Where, How. AOSTRA Seminar on Underground Excavation in Oilsands, University of Alberta, Edmonton, Alberta, 23p.

Brooker, E.W. and Khan, F. 1980. Design and Performance of Oilsand Surface Mine Slopes, Oilsand GeoScience Conference, University of Alberta, Edmonton, Alberta, 40p.

Cameron, A.E. 1918. Explorations in the Vicinity of Great Slave Lake, Geological Survey of Canada, Report 1917, Part C, pp. 21-28.

Carrigy, M.A. 1959. Geology of the McMurray Formation, Part III, General Geology of the McMurray Area, Memoir 1, Research Council of Alberta, Geological Division, 130p.

Carrigy, M.A. 1963. Petrology of Coarse-Grained Sands in the Lower Part of the McMurray Formation, in the K.A. Clark Volume on the Athabasca Oilsands, Research Council of Alberta, Information Series 45, pp. 43-55.

Carrigy, M.A. 1966. Lithology of the Athabasca Oilsands, Research Council of Alberta, Bulletin 18, 47p.

Carrigy, M.A. 1973. Mesozoic Geology of the Fort McMurray Area, in Guide to the Athabasca Oilsands Area, Alberta Research Council, Information Series 65, pp. 77-103.

Carrigy, M.A. and Kramers, J.W. 1973. Editors, Guide to the Athabasca Oilsands Area, Research Council of Alberta, Information Series No. 65, 213p.

Charlwood, R.G., Byrne, P.M., McKinlay, D.W. and Varoglu, E. 1980. Thermal-Geomechanical Analyses and Criteria for the Design of a Mine-Assisted Heavy Oil Recovery Facility, Applied Oilsands Geoscience Conference, Edmonton, Alberta, 57p.

Coates, D.F. 1981. Rock Mechanics Principles, Energy, Mines and Resources Canada, Monograph 874, 411p.

Crickmay, C.H. 1957. Elucidation of Some Western Canadian Devonian Formations, Imperial Oil Co. Ltd., Calgary, Alberta, 14p.

Crickmay, C.H. 1966. Devonian Time in Western Canada, E. deMille Books, Calgary, Alberta, pp. 1-22.

Deere, D.U. 1964. Technical Description of Rock Cores for Engineering Purposes, Rock Mechanics and Engineering Geology, Volume 1, No. 1, pp. 17-22.

Devenny, D.W. and Raisbeck, J.M. 1980. Rock Mechanics Considerations for In-Situ Development of Oilsands, 13th Canadian Rock Mechanics Symposium, Canadian Institute of Mining and Metallurgy Special Volume 22, pp. 90-97.

Dolph, J. 1981. Personal Communication, Gulf Canada Resources Inc., Calgary, Alberta.

Dunn, C.E. 1982. Geology of the Middle Devonian Dawson Bay Formation in the Saskatchewan Potash Mining District, Saskatchewan, Saskatchewan Energy and Mines Report 194, 117p.

Dusseault, M.B. 1977. The Geotechnical Characteristics of the Athabasca Oilsands, Ph.D. Thesis, Department of Civil Engineering, University of Alberta, Edmonton, Alberta, 472 pp.

Dusseault, M.B. 1977. Stress State and Hydraulic Fracturing in the Athabasca Oilsands, Journal of Canadian Petroleum Technology, Volume 16, No. 3, pp. 19-27.

Dusseault, M.B. and Morgenstern, N.R. 1978. Characteristics of Natural Slopes in the Athabasca Oilsands, Canadian Geotechnical Journal, Volume 15, No. 2, pp. 202-216.

Dusseault, M.B. and Scafe, D. 1979. Mineralogical and Engineering Index Properties of the Basal McMurray Formation Clay Shales, Canadian Geotechnical Journal, Volume 16, No. 2, pp. 285-295.

Dusseault, M.B. and Simmons J.V. 1982. Injection-Induced Stress and Fracture Orientation Changes, Canadian Geotechnical Journal, Volume 19, No. 4, pp. 483-494.

Ells, S.C. 1932. Exploration of Bituminous Sands Areas in Northern Alberta, Canadian Mines Bureau Report 72, pp. 107-134.

Fong, G. 1959. Type Section; Swan Hills Member of the Beaverhill Lake Formation, Alberta Society of Petroleum Geologists, Volume 7, No. 5, pp. 95-108.

Fong, G. 1960. Geology of the Devonian Beaverhill Lake Formation, Swan Hills Area, Alberta, Canada, American Association of Petroleum Geology Bulletin, Volume 44, No. 2, pp. 195-209.

Ford, D.C. 1971. Characteristics of Limestone Solution in the Southern Rocky Mountain and Selkirk Mountains; Alberta and British Columbia, Canadian Journal of Earth Science, Volume 8, No. 6, pp. 585-610.

Franklin, J.A. and Hungr, O. 1978. Rock Stresses in Canada: Their Relevance to Engineering Projects, Rock Mechanics Supplement 6, Springer-Verlag, pp. 25-46.

Godfrey, J.D. 1958. Aerial Photographic Interpretation of Precambrian Structures North of Lake Athabasca, Research Council of Alberta, Geological Division, Bulletin 1, 19p.

Gorrell, H.A. 1974. Coordinator-Regional Hydrogeological Study, McMurray Oilsands Area, Alberta, Oilsands Environmental study Group, 92p.

Gough, D.I. and Bell, J.S. 1981. Stress Orientations from Oilwell Fractures in Alberta and Texas. Canadian Journal of Earth Sciences, Volume 18, No. 3, pp. 638-645.

Govett, G.J.S. 1961. Occurrence and Stratigraphy of Some Gypsum and Anhydrite Deposits in Alberta, Research Council of Alberta, Bulletin 7, 62p.

Green, R. 1958. Precambrian Basement Features in Northern Alberta, Research Council of Alberta, Bulletin 3, 12p.

Greiner, H.R. 1956. Methy Dolomite of Northeastern Alberta: Middle Devonian Reef Formation, Bulletin of the American Association of Petroleum Geologists, Volume 40, No. 9, pp. 2057-2080.

Gressly, A. 1838. Observations Geologiques Sur Le Jura Soleurois, Neue Denkschr. Allg. Schweiz. Ges. Ges. Naturw. 2, pp. 1-112.

Grim, R.E. 1968. Clay Mineralogy, Second Edition, McGraw-Hill Book Co., New York, 596p.

Hackbarth, D.A. 1977. Regional Hydrogeology of the Athabasca Oilsands Area, Alberta, Canada, in the Oilsands of Canada and Venezuela, Canadian Institute of Mining and Metallurgy, Special Volume 17, D.A. Redford and A.G. Winestock, Editors, pp. 87-102.

Hackbarth, D.A. 1978. Hydrogeological Concerns in Underground Excavation, Athabasca Oilsands Area, AOSTRA Seminar on Underground Excavation in Oilsands, University of Alberta, Edmonton, Alberta, 36 p.

Hackbarth, D.A. and Nastasa, N. 1979. Hydrogeology of the Athabasca Oilsands Area, Alberta, Alberta Research Council, Bulletin 38, 39p.

Hardy, R.M. and Associates Ltd. 1977. Feasibility Study for the Underground Mining of Oilsand, Report to the Department of Energy, Mines and Resources, 118 p.

Harrison, R. 1982. Personal Communication, Alberta Research Council, Geological Survey.

Haston, J.A. 1978. Mine Assisted In-Situ Processing, AOSTRA Seminar on Underground Excavation in Oilsands, University of Alberta, Edmonton, Alberta, 21p.

Hoek, E. and Bray, J.W. 1981. Rock Slope Engineering, Revised Third Edition, Institute of Mining and Metallurgy, London, England, 358p.

Hoek, E. and Brown, E.T. 1980. Empirical Strength Criterion for Rock Masses, Journal of the Geotechnical Engineering Division, American Society of Civil Engineering Volume 106, GT 9.

Hoek, E. and Brown, E.T. 1980. Underground Excavations in Rock, Institute of Mining and Metallurgy, London, England, 527p.

Holzhausen, G.R., Wood, M.D., Raisbeck, J.M. and Card, C.C. 1980. Results of Deformation Monitoring During Steam Stimulation in a Single Well Test, Applied Oilsands Geoscience Conference, University of Alberta, Edmonton, Alberta, 40p.

Hume, G.S. 1947. Results and Significance of Drilling Operations in the Athabasca Bituminous Sands. Transactions of the Canadian Institute of Mining and Metallurgy, Volume 50, pp. 298-330.

Hume, G.S. 1951. Possible Lower Cretaceous Origin of Bitumen in Bituminous Sands of Alberta, Proceedings of the Athabasca Oilsands Conference, Edmonton, Alberta, pp. 66-76.

Jakucs, L. 1977. Morphogenetics of Karst Regions, J. Wiley and Sons, New York, 284p.

James, D.P. 1979. Chapters 9, 10 in Facies Models, Reprint Series 1, Geoscience Canada, R.G. Walker, Editor.

James, D.P. and Oliver, T.A. 1978. The Sedimentology of the McMurray Formation, East Athabasca, in the Oilsands of Canada-Venezuela, D.A. Redford and A.G. Winestock, Editors, Canadian Institute of Mining and Metallurgy, Special Volume 17, pp. 17-27.

Kidd, F.A. 1951. Geology of the Bituminous Sand Deposits of the McMurray Area, Alberta, Proceedings of the Athabasca Oilsands Conference, Edmonton, Alberta, pp. 30-39.

Khan, F.Z., Fair, A.E. and Cuddy, G. 1982. Depressurization and Basal Highwall Stability at Syncrude Mine, Seminar of Geotechnical Aspects of Mine Design and Tailings Containment, University of Calgary, Calgary, Alberta, 31p.

Lauffer, H. 1958. Gebirgsklassifizierung Fur Den Stollenbau, Geologie und Bauwesen, Volume 24, No. 1, pp. 46-51.

Link, T.A. 1951. Source of Oil in Oilsands of Athabasca River, Alberta, Canada, Proceedings of Athabasca Oilsands Conference, Edmonton, Alberta, pp. 55-66.

Macoun, J. 1877. Geological and Topographical Notes on the Lower Peace and Athabasca Rivers, Geological Survey of Canada Report on Progress, 1875-1876, pp. 87-95.

Martin, R. and Jamin, F.G.S. 1963. Paleogeomorphology of the Buried Devonian Landscape in Northeastern Alberta, in K.A. Clark Volume, Alberta Research Council, Information Series 45, M.A. Carrigy, Editor, pp. 31-43.

Mason, B. 1966. Principles of Geochemistry, Third Edition, John Wiley and Sons Inc New York, 329p.

Mathews, K.E. 1980. Potential for the Underground Mining of Oil Sands in Canada, Rockstore 80, Proceedings of the International Symposium on Subsurface Space for Environmental Protection, Low Cost Storage and Energy Savings, Stockholm, Sweden, 8p.

Mathews, K.E., Rawlings, G.E. and Bharti, S. 1980. Investigation of the Geotechnical and Mining Characteristics of the Devonian Limestones, Athabasca Oilsands Area, Applied Oilsands Geoscience Conference, Edmonton, Alberta, 41p.

McConnell, R.G. 1983. Report on a Portion of the District of Athabasca Comprising the Country Between Peace River and Athabasca River North of Lesser Slave Lake, Geological Survey of Canada, Annual Report, 1890-1891, Volume 5, pp. 1-67.

McDonald, W.D. 1947. A Comparative Study of the Waterways and Older Formations of the McMurray Area, Master's Thesis, Department of Geology, University of Alberta, Edmonton, Alberta.

McDonald, W.D. 1955. The Waterways Formation in the Subsurface at McMurray, Alberta, Journal of the Alberta Society of Petroleum Geologists, Volume 3, No. 7, pp. 105-107.

McGarr, A. and Gay, N.C. 1978. State of Stress in the Earth's Crust, Annual Review of Earth Planetary Science, 1978.6, pp. 405-436.

McGehee, J.R. 1949. Pre-Wat ways Paleozoic Stratigraphy of Alberta Plains, Bulletin of the American Association of Petroleum Geologists, Volume 33, No. 4,1 pp. 603-613.

Mogi, K. 1972. Fracture and Flow of Rocks in the Upper Mantle, Tectonophysics, 13, pp. 541-568.

Mossop, G.D. 1978. Geological Controls on Reservoir Heterogeneity-Athabasca Oilsands, AOSTRA Seminar on Underground Excavation in Oilsands, University of Alberta, Edmonton, Alberta, 27p.

Mossop, G.D. 1980. Oilsands Geology for Engineers, Alberta Research Council, Geological Survey, Unpublished Short Course Notes, University of Calgary, Calgary, Alberta.

Nauss, A.W. 1950. Regional Cross-Section Through the Reef Fields of Alberta, Oil in Canada, Volume 11, No. 47, pp. 46-48.

Norris, A.W. 1963. Devonian Stratigraphy of Northeastern Alberta and Northwestern Saskatchewan, Geological Survey of Canada, Memoir 313, 168p.

Norris, A.W. 1973. Paleozoic (Devonian) Geology of Northeastern Alberta and Northwestern Saskatchewan, Guide to the Athabasca Oilsands area, Alberta Research Council, Information Series 65, pp. 15-76.

Norris, A. W. 1981. Personal Communication, Institute of Sedimentary and Petroleum Geology, Calgary, Alberta.

Norris, A.W. and Uyeno, T.T. 1981. Stratigraphy and Paleontology of the Lowermost Upper Devonian Slave Point Formation of Lake Claire and the Lower Upper Devonian Waterways Formation on Birch River, Northeastern Alberta. Geological Survey of Canada, Bulletin 334, 53p.

Obert, L. and Stephenson, D.E., 1965. Stress Conditions under which Core Discing Occurs, Society of Mining Engineers, Transactions, 232, pp. 227-234.

Overbey, W.K. and Rough, R.L. 1971. Prediction of Oil and Gas Bearing Rock Fractures From Surface Structural Features, United States Bureau of Mines, Report of Investigations 7500, Washington, 14p.

Ozoray, G. 1977. The Athabasca Carbonate and Evaporite Buried Karst, Proceedings of the International Association of Hydrogeologists, 12th International Conference, Huntsville, Alabama, pp. 85-98.

Ozoray, G., Hackbarth, D. and Lytviak, A.T. 1980. Hydrogeology of the Bitumount-Namur Lake Area, Alberta, Alberta Research Council. Earth Sciences Report 78-6, 11p.

Patching, T., Jeremic, M. and Stimpson, B. 1978. On the Possibility of Mining Oilsand by Underground Means, AOSTRA Seminar on Underground Excavation in Oilsands, University of Alberta, Edmonton, Alberta, 16p.

Price, N.J. 1966. Fault and Joint Development in Brittle and Semi-Brittle Rock, Pergamon Press, London, 176p.

Ramberg, H. 1955. Natural and Experimental Boudinage and Pinch and Swell Structures, Journal of Geology, Volume 63, No. 6, pp. 512-527.

Ramsay, J.G. 1967. Folding and Fracturing of Rocks, McGraw-Hill Book Co., London, 568p.

Reading, H.G. 1978. Sedimentary Environments and Facies, Chapter 2, Blackwell, London, pp. 4-15.

Reineck, H.E. and Singh, I.B. 1980. Depositional Sedimentary Environments, Second Edition, Springer-Verlag, New York, 439p.

Richardson, J. 1851. Arctic Searching Expedition for Sir John Franklin, Geological Notes along the Athabasca River, Longman, Brown, Green and Longmans, London, Volume 1, pp. 109-141, Volume 2, pp. 199-211.

Roesner, E.K. and Poppen, S.A. 1978. Shaft Sinking and Tunnelling in the Oilsands of Alberta, AOSTRA Seminar on Underground Excavation in Oilsands, University of Alberta, Edmonton, Alberta, 36p.

Rudkin, R.A. 1964. Lower Cretaceous, Chapter II in Geological History of Western Canada, Alberta Society of Petroleum Geologists, Calgary, pp. 156-168.

Scott, J.S. 1973. Engineering Geology of Canadian Karst, Report to the International Association of Engineering Geology, Working Group on Engineering Geology Problems in Karst Regions.

Selley, R.C. 1976. An Introduction to Sedimentology, Academic Press, Yew York, 408p.

Selley, R.C. 1978. Ancient Sedimentary Environments, Second Edition, Chapman and Hall, London, 237p.

Settari, A. and Raisbeck, J.M. 1979. Fracture Mechanics Analysis in In-Situ Oilsands Recovery, Journal of Canadian Petroleum Technology, Volume 18, pp. 85-94.

Sinha, R.P. 1976. A Study of Joints in the Fort McMurray-Bitumount Area, Alberta, for the Syncrude Mine, 14 p.

Spencer, E.W. 1977. Introduction to the Structure of the Earth, Second Edition, McGraw-Hill Book Company, New York, 640p.

Sproule, J.C. 1932. Geological Reconnaissance of Part of the McMurray Asphalt Deposit, Northern Alberta, Master's Thesis on file at Mines Branch Library, Department of Mines and Technology Survey.

Sproule, J.C. 1981. The McMurray Formation in its Relation to Oil Occurrences, Proceedings of the Athabasca Oilsands Conference, Edmonton, Alberta, pp. 6-25.

Sproule, J.C. 1956. Granite Wash of Northern Alberta, Journal of Alberta Society of Petroleum Geologists, Volume 4, pp. 197-203.

Stelck, C.R. 1975. Basement Control of Cretaceous Sand Sequences in Western Canada, in The Cretaceous System in the Western Interior of North America, W.G.E. Caldwell, Editor, Geological Association of Canada, Special Paper No. 13, pp. 427-441.

Stephenson, H.G. 1978. An Evaluation of the Underground Approach to Oilsand Development, AOSTRA Seminar on Underground Excavation in Oilsands, University of Alberta, Edmonton, Alberta, 17p.

Stewart, G.A. 1963. Geological Controls on the Distribution of Athabasca Oil Sand Reserves, in the K.A. Clark Volume on the Athabasca Oil Sands, M.A. Carrigy (Editor). Research Council of Alberta, Information Series No. 45, pp. 15-27.

Stoakes, F.A. 1980. Nature and Control of Shale Basin Fill and Its Effect on Reef Growth and Termination: Upper Devonian Duvernay and Ireton Formations of Alberta, Canada, Bulletin of Canadian Petroleum Geology, Volume 28, No. 3, pp. 345-410.

Sweeting, M.M. 1972. Karst Landforms, MacMillan Publishing Co., New York, 362p.

Terzaghi, K. 1946. Rock Defects and Loads on Tunnel Supports, in Rock Tunnelling with Steel Supports, R.V. Proctor and T. White, Editors, pp. 15-99.

Thorez, J. 1976. Practical Identification of Clay Minerals: A Handbook for Teachers and Students in Clay Mineralogy, G. LeLotte, Dison, 90p.

Tsui, P.C. 1982. Deformation, Ground Subsidence and Slope Movements Along Salt River Escarpment in Wood Buffalo National Park, Master's Thesis, Department of Geology, University of Alberta, Edmonton, Alberta, 140p.

Warren, P.S. 1933. Age of Devonian Limestone at Fort McMurray, Canadian Fie . Naturalist, Volume 47, No. 8, pp. 148-149.

Warren, P.S. 1951. Some Stratigraphic Features of the Upper Devonian Sequence of the Canadian Western Plains, Proceedings of the Athabasca Oilsands Conference, Edmonton, Alberta, pp. 66-76.

Wickham, G.E., Tiedemann, H.R. and Skinner, E.H. 1972. Support Determination Based on Geological Predictions, Proceedings of the First North American Rapid Excavation and Tunnelling Conference, American Institute of Mining Engineers, New York, pp. 43-64.

Williams, K.A. 1980. A Geotechnical Assessment of the Waterways Formation for Underground Mining, Master's Thesis, Department of Mining Engineering, University of Alberta, Edmonton, Alberta.

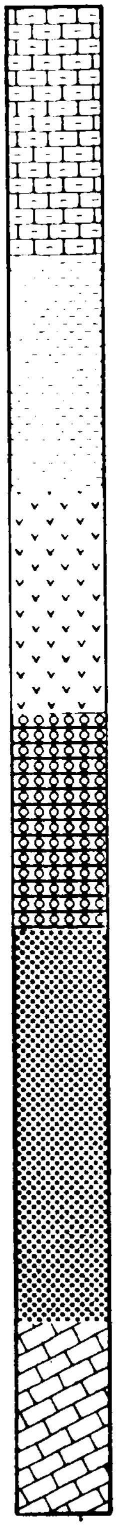
Williams, K.A., Stimpson, B., Patching, T. and Jeremic, M. 1980. A Geotechnical Study of the Waterways Formation Limestone Beneath the Athabasca Oilsands, AOSTRA Research Report.

Wilson, J.L. 1975. Carbonate Facies in Geologic History, Springer-Verlag, New York, 471p.

Win, U. 1976. Site Investigation for Dams in Limestone Terrain, Master of Engineering Report, Department of Civil Engineering, University of Alberta, Edmonton, Alberta, 101p.

APPENDIX A

LOG KEY



Rock Type A - Massive to Nodular Argillaceous Limestones and Finely Interbedded Limestone-Micrite

Rock Type B - Calcareous Shale

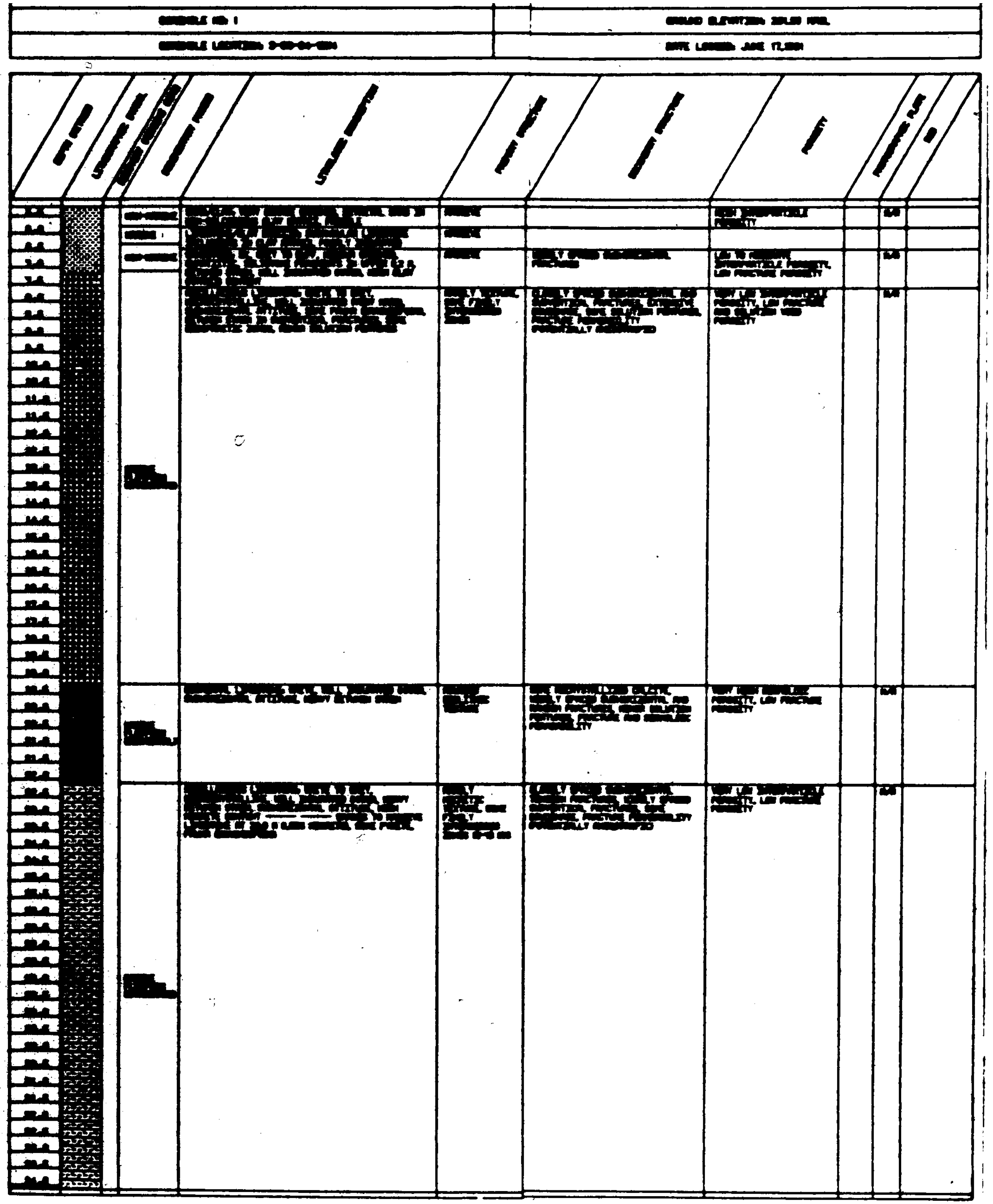
Rock Type C - Limestone Intraclast Breccia

Rock Type D - Biohermal Limestone

Rock Type E - Uncemented Quartz Sand

Rock Type F - Unconsolidated Sediments

Disturbed (Brecciated) Carbonate



DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 13	GROUND ELEVATION: 316.53 MASL
COREHOLE LOCATION: 15-25-94-10W4	DATE LOGGED: SEPTEMBER 14,1981

Depth (metres) scale: 49.5, 50.0, 50.5, 51.0, 51.5, 52.0, 52.5, 53.0, 53.5, 54.0, 54.5, 55.0, 55.5, 56.0, 56.5, 57.0, 57.5, 58.0, 58.5, 59.0, 59.5, 60.0, 60.5, 61.0, 61.5, 62.0, 62.5, 63.0, 63.5, 64.0, 64.5, 65.0, 65.5, 66.0

Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: WHITE, BIOLITHIC TEXTURE, WELL INDURATED (HARD), HEAVY BITUMEN STAIN, ABUNDANT FAUNA	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL FRACTURES, BIOMOLDIC AND FRACTURE PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		--- --- --- 013 --- --- --- 063
MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA: GREY, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS CLAY MATRIX, WELL CEMENTED, SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA	NODULAR, BRECCIATED TEXTURE	WIDELY SPACED SUBHORIZONTAL FRACTURES, SOME DESSICATION FRACTURES, MINOR BOUDINAGE	LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A,
MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: WHITE TO GREY, BIOLITHIC TEXTURE, WELL INDURATED (HARD), HEAVY BITUMEN STAIN, MINOR SOLUTION FEATURES, ABUNDANT FAUNA	MOUNDED BIOLITHIC TEXTURE	MINOR SOLUTION PIPE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		--- --- --- 788 --- --- --- 568
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		--- --- --- 045 --- --- --- 065 --- --- --- 255
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA	FINELY INTERBEDDED (CM) LIMESTONE/SHALE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		--- --- --- 315

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 20	GROUND ELEVATION: 312.85 MASL
COREHOLE LOCATION: 8-14-84-16W4	DATE LOGGED: JUNE 9,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (PERIODS CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
41.7										
42.4, 43.1, 43.8, 44.5, 45.2, 45.9			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: OLIVE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), MINOR WEATHERING ALONG FRACTURES, SOME CONVOLUTED BEDDING, MINOR SOLUTION FEATURES	MARBLY TO NODULAR MICRITIC TEXTURE, SOME LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME CONVOLUTED BEDDING, SOLUTION FEATURES	VERY LOW INTERPARTICLE, FRACTURE, AND SOLUTION POROSITY		N/A	
46.6, 47.3, 48.0, 48.7, 49.4, 50.1, 50.8, 51.5, 52.2			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, SOME HARD FERROMAGNESIAN (?) INCLUSIONS	NODULAR TO FINELY INTERBEDDED WITH MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, RANDOM FRACTURES ABOUT NODULES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	
52.9, 53.6, 54.3, 55.0			MARINE PLATFORM ([illegible])	LIMESTONE INTRACLAST BRECCIA: GREY, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS CLAY MATRIX, WELL INDURATED (VERY HARD)	DISTURBED BRECCIATED TEXTURE	SOME BOUDINAGE, SOME LAMINAE, RANDOM DESICCATION FRACTURES, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	
55.7, 56.4, 57.1			MARINE PLATFORM ([illegible])	BIOHERMAL LIMESTONE: GREY, BIOLITHIC TEXTURE, WELL INDURATED (VERY HARD), ABUNDANT FAUNA, HEAVY BITUMEN STAIN, SOME SOLUTION FEATURES	ROUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, MINOR SOLUTION FEATURES	HIGH [illegible] POROSITY, LOW FRACTURE POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 23	GROUND ELEVATION: 318.00 MASL
COREHOLE LOCATION: 12-11-94-10W4	DATE LOGGED: SEPTEMBER 18,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (BROKEN CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
29.7, 30.4, 31.1, 31.8, 32.5, 33.2, 33.8, 34.6, 35.3, 36.0, 36.7			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN, SOME FAUNA, UPPER 0.4 M WEATHERED (DISCOLORED)	MARBLY TO NODULAR MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
37.4, 38.1, 38.8, 39.5, 40.2			MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA; GREY, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS SHALE MATRIX, WELL BEDDED (SUBHORIZONTAL), WELL CEMENTED (HARD), HEAVY BITUMEN STAIN	DISTURBED BRECCIATED TEXTURE, SUBHORIZONTAL BEDDING	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
40.8, 41.6, 42.3, 43.0, 43.7			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, BIOLITHIC TEXTURE, WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN, SOME ARGILLACEOUS STRINGERS	MOUNDED BIOLITHIC TEXTURE, INTERBEDDED ARGILLACEOUS STRINGERS	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	HIGH BIOMOLDIC POROSITY, MODERATE FRACTURE POROSITY		N/A	
44.4, 45.1, 45.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 25	GROUND ELEVATION: 321.52 MASL
COREHOLE LOCATION: 10-12-94-10W4	DATE LOGGED: SEPTEMBER 17,1981

Depth (metres) scale: 52.5, 53.0, 53.5, 54.0, 54.5, 55.0, 55.5, 56.0, 56.5, 57.0, 57.5, 58.0, 58.5, 59.0, 59.5, 60.0, 60.5, 61.0, 61.5, 62.0, 62.5, 63.0, 63.5, 64.0, 64.5, 65.0, 65.5, 66.0, 66.5, 67.0, 67.5, 68.0

Lithographic Symbol	Recovery (Missing Core)	Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
		MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, SOME WEATHERING IN UPPER 0.5 M DISCOLORATION	MARBLY MICRITIC TEXTURE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		70%
		MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA: WHITE, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS CLAY MATRIX, MOD. WELL INDURATED, BITUMEN STAIN	DISTURBED BRECCIATED TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
		MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD)	MARBLY TEXTURE				
		MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: WHITE, BIOLITHIC TEXTURE, WELL INDURATED (HARD), BITUMEN STAIN, LOW ARGILLACEOUS CONTENT	ROUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		81%
			LIMESTONE BRECCIA					
			BIOHERMAL LIMESTONE					
		MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, DISTURBED (BRECCIATED) TEXTURE AT 61 M	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, BRECCIATED COLLAPSE ZONE AT 61	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
		MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE, SOME LAMINAR ARGILLACEOUS ZONES	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		57%

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 33	GROUND ELEVATION: 317.33 MASL
COREHOLE LOCATION: 8-33-94-9W4	DATE LOGGED: JUNE 17,1981

Depth scale (metres): 103.6, 104.2, 104.8, 105.4, 106.0, 106.6, 107.2, 107.8, 108.4, 109.0, 109.6, 110.2, 110.8, 111.4, 112.0, 112.6, 113.2, 113.8, 114.4, 115.0, 115.6, 116.2, 116.8, 117.4, 118.0, 118.6, 119.2

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODA), WEATHERED UPPER 0.7 M	MARBLY TO NODULAR MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A
MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE: OLIVE TO GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SLIGHTLY WEATHERED ALONG DISCONTINUITIES, TRACE OF PYRITE	LAMINAE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME INCLINED COMPRESSION (?) FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE NODULES	FINELY INTERBEDDED (CM) LIMESTONE/SHALE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A
	ARGILLACEOUS LIMESTONE: MARBLY MICRITIC TEXTURE					
	CALCAREOUS SHALE					
	ARGILLACEOUS LIMESTONE					
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HIGH ARGILLACEOUS CONTENT, SOME PYRITE NODULES	MARBLY TO NODULAR MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 35	GROUND ELEVATION: 327.0 MASL
COREHOLE LOCATION: 12-35-94-9W4	DATE LOGGED: JUNE 17,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	SECONDARY BINDING CORD	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	ROD
121.6, 122.2			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SLIGHTLY WEATHERED (DISCOLORED), SOME PYRITE, CARBONACEOUS PARTICLES ON UPPER CONTACT	LAMINAE	WEATHERING, WIDELY SPACED SUBHORIZONTAL/SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
122.8, 123.4, 124.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SOME FAUNA	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
124.6, 125.2, 125.8, 126.4, 127.0, 127.6, 128.2, 128.8, 129.4, 130.0, 130.6, 131.2, 131.8, 132.4, 133.0, 133.6, 134.2			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE; OLIVE TO GREY, FISSILE, WELL CEMENTED (HARD), SOME INTERBEDDED BIOLITHIC UNITS, SUBHORIZONTAL ATTITUDE, SOME PYRITIC VEINS/NODULES	LAMINAE, INTERBEDDED BIOLITHIC UNITS	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
134.8				BIOLITHIC ZONE					
135.4, 136.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	FINELY INTERBEDDED TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 38	GROUND ELEVATION: 328.1 MASL
COREHOLE LOCATION: 13-38-84-5W4	DATE LOGGED: JUNE 17,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (CORING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD	
122.7 123.4 124.1 124.8 125.5 126.2			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY TO OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE NODULES, SLIGHT WEATHERING	LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
126.9 127.6 128.3 128.9 129.7 130.4 131.1 131.8 132.5 133.2			MARINE PLATFORM (CARBONATE/	ARGILLACEOUS LIMESTONE/SHALE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODA), SOME PYRITE VEINS	FINELY INTERBEDDED (CM) TO MARBLY MICRITIC TEXTURES	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE PERMEABILITY		N/A	
133.9 134.6 135.3 136.0 136.7 137.4 138.1			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE, SOME RECRYSTALLIZED CALCITE	MARBLY TO NODULAR MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 48	GROUND ELEVATION: 321.72 MASL
COREHOLE LOCATION: 3-29-94-SW4	DATE LOGGED: SEPTEMBER 14,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERIODS CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
61.0									
[illegible] – 62.0			[illegible]	[illegible] LIMESTONE; WHITE TO BUFF, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME MICRITE, HEAVY BITUMEN STAIN, MODERATELY WEATHERED, EXTENSIVE KARST SOLUTION	ROUNDED [illegible] TEXTURE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, EXTENSIVE KARST SOLUTION FEATURES, FRACTURE AND SOLUTION VOID PERMEABILITY	HIGH [illegible] POROSITY, LOW FRACTURE POROSITY		— — [illegible]
[illegible] – [illegible]			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME THIN FOSSILIFEROUS BEDS, PYRITE RIMS, SOME WELL BEDDED CALCAREOUS, MED. GRAINED QUARTZ SANDS, POTENTIAL HARDGROUND AT 68.5 M, SHALY AT 73 M	MAINLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURES, OCC. FOSSILIFEROUS BED	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED INCLINED COMPRESSION (?) FRACTURES, FRACTURE PERMEABILITY	MODERATE FRACTURE, BIOMOLDIC AND INTERGRANULAR (GRADED) POROSITY		N/A
75.4				CALCAREOUS QUARTZ SAND					
[illegible] – 77.2			MARINE (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED, SUBHORIZONTAL ATTITUDE	MAINLY/FINELY INTERBEDDED (CM) MICRITIC TEXTURE				
77.8 – 78.4			MARINE (SHALE)	CALCAREOUS SHALE; GREY, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME CARBONATE NODULES	NODULAR TO LAMINAR	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES	VERY LOW INTERPARTICLE/FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 58	GROUND ELEVATION: 334.4 MASL
COREHOLE LOCATION: 8-28-84-8W4	DATE LOGGED: JUNE 18,1981

Depth markers (DEPTH METRES): 101.7, 102.4, 103.1, 103.8, 104.5, 105.2, 105.9, 106.6, 107.3, 108.0, 108.7, 109.4, 110.1, 110.8, 111.5, 112.2, 112.9, 113.6, 114.3, 115.0, 115.7, 116.4, 117.1, 117.8, 118.5

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (DASHED CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
101.7										
102.4 – 103.1			MARINE [illegible]	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SOME PYRITE, SOME RECRYSTALLIZED CALCITE, TRACE OF FAUNA (BRACHIOPODS)	MARBLY TO NODULAR MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
103.8				NON-CALCAREOUS SHALE; GREY TO OLIVE, BEDDED (LAMINAR), MODERATELY CEMENTED, PYRITIC	BEDDING LAMINAE	DESICCATION FRACTURES	VERY LOW INTERPARTICLE POROSITY		N/A	
104.5 – 114.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), PYRITIC, SOME RECRYSTALLIZED CALCITE, UNDISTURBED	MARBLY TO NODULAR MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY		N/A	
114.3 – 118.5			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, PYRITIC	FINELY INTERBEDDED (CM) LIMESTONE/SHALE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, EXTENSIVE BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 58	GROUND ELEVATION: 321.58 MASL
COREHOLE LOCATION: 6-28-94-5W4	DATE LOGGED: SEPTEMBER 16, 1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
67.6									
[illegible]				NON-CALCAREOUS CLAY SHALE					
[illegible]			MARINE PLATFORM [illegible]	CALCAREOUS SHALE: GREY TO RUST [illegible], FISSILE, WELL CEMENTED [illegible], SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA, BITUMEN STAIN	LAMINAR TO NODULAR TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME INCLINED COMPRESSION (?) FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	39B	
[illegible]			MARINE [illegible]	LIMESTONE [illegible] BRECCIA: WHITE, SUBANGULAR LIMESTONE INCLUSIONS IN GREY, CALCAREOUS CLAY MATRIX, MASSIVE, POORLY INDURATED	DISTURBED BRECCIATED TEXTURE	MINOR KARST SOLUTION FEATURES (PIPES), WIDELY SPACED RANDOM FRACTURES	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	9B	
[illegible]			MARINE PLATFORM [illegible]	[illegible] LIMESTONE: WHITE, OOLITHIC TEXTURE, WELL INDURATED (VERY HARD), HIGHLY ARGILLACEOUS IN UPPER METRE, SOME FAUNA, HEAVY BITUMEN STAIN	MOUNDED OOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		
[illegible]			NON-MARINE	NON-CALCAREOUS CLAY: GREY, MASSIVE, POORLY CEMENTED					
[illegible]			NON-MARINE	QUARTZ SAND: BUFF, MEDIUM TO COARSE GRAINED, POORLY CEMENTED (FRIABLE), UNIFORMLY GRADED, SUBROUNDED GRAINS, SOME [illegible], BITUMEN STAIN, TRACE OF SILT/CLAY MATRIX	WELL BEDDED		HIGH INTERPARTICLE POROSITY		
[illegible]			NON-MARINE	NON-CALCAREOUS CLAY					
[illegible]			MARINE PLATFORM [illegible]	ARGILLACEOUS LIMESTONE					
70.2				QUARTZ SAND					
70.7			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS)	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, MINOR KARST SOLUTION FEATURES (PIPES), FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY, LOW SOLUTION VOID POROSITY	N/A	
71.3									
71.8									
72.4									
72.8									
73.6									
74.0									
74.6									
75.1									
75.7									

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 58	GROUND ELEVATION: 322.81 MASL
COREHOLE LOCATION: 8-21-94-9W4	DATE LOGGED: SEPTEMBER 15,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (BOXES CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
133.7 134.4 135.1 135.8 136.5 137.2 137.9 138.6 139.3 140.0 140.7 141.4 142.1 142.8 143.5 144.2 144.9 145.6 146.3 147.0 147.7 148.4 149.1 149.8 150.5 151.2 151.9 152.6 153.3 154.0 154.7			NON-MARINE	NON-CALCAREOUS CLAY,SILT,SAND AND COAL					
			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, PYRITE NODULES (INFILLING FRACTURE POROSITY), SOME FAUNA (BRACHIOPODS), RECRYSTALLIZED CALCITE IN BIOMOLDIC POROSITY	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND BIOMOLDIC POROSITY	525 829 443	
			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE: GREY, FISSILE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS AT 148 M, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, PYRITE NODULES, OCC. BRACHIOPOD	POORLY DEFINED LAMINAE/BEDDING, SOME NODULAR LIMESTONE TEXTURES	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD)	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY			
				CALCAREOUS SHALE					
			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	NODULAR TO LAMINAR TEXTURE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 72	GROUND ELEVATION: 324.49 MASL
COREHOLE LOCATION: 14-7-94-9W4	DATE LOGGED: SEPTEMBER 18,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
81.6, 82.2, 82.8, 83.4, 84.0, 84.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, WEATHERED (DISCOLOURED) IN UPPER 0.3 M, LIGHT BITUMEN STAIN, SOME FAUNA	MARBLY MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, WEATHERING, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A
85.2, 85.8, 86.4			MARINE [illegible]	CALCAREOUS SHALE, GREY, SUBTLE FISSILITY, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, PYRITE NODULES, POTENTIAL HARDGROUND SURFACE AT 86.0 M	FINELY INTERBEDDED (CM) TO NODULAR TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
87.0, 87.6, 88.2, 88.8, 89.4, 90.0, 90.6, 91.2, 91.8			MARINE PLATFORM (CARBONATE)	GRADES TO INTERBEDDED CALCAREOUS SHALE/LIMESTONE STRINGERS	MARBLY TO FINELY INTERBEDDED (CM) SHALE/LIMESTONE TEXTURE	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES,FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
92.4, 93.0, 93.6, 94.2, 94.8			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE, GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
95.4, 96.0, 96.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	FINELY INTERBEDDED (CM) SHALE/LIMESTONE	BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 78	GROUND ELEVATION: 331.78 MASL
COREHOLE LOCATION: 7-9-94-9W4	DATE LOGGED: JUNE 12,1981

Depth (metres): 133.7, 134.4, 135.1, 135.8, 136.5, 137.2, 137.9, 138.6, 139.3, 140.0, 140.7, 141.4, 142.1, 142.8, 143.5, 144.2, 144.9, 145.6, 146.3, 147.0, 147.7, 148.4, 149.1, 149.8, 150.5, 151.2

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
MARINE PLATFORM SHALES	CALCAREOUS SHALE: OLIVE, FISSILE, WELL CEMENTED (HARD), SLIGHTLY WEATHERED (DISCOLORED), SOME LIMESTONE INTERBEDS	LAMINAE, SOME FINELY INTERBEDDED (CM) LIMESTONE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED SUBVERTICAL COMPRESSION (?) FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
	FRAGMENTED LIMESTONE: DISTURBED BRECCIATED TEXTURE	POTENTIAL UNCONFORMITY					
MARINE PLATFORM CARBONATES	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS)	MARLY TO NODULAR MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
MARINE PLATFORM SHALES	CALCAREOUS SHALE: OLIVE TO GREY, FISSILE, WELL CEMENTED (HARD), SOME PYRITE	LAMINAE, SOME FINELY INTERBEDDED (CM) LIMESTONE STRINGERS	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY			
MARINE PLATFORM CARBONATES	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), SOME PYRITE NODULES	MARLY MICRITIC TEXTURE, SOME FINELY INTERBEDDED (CM) SHALE STRINGERS	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND BIOMOLDIC POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 78	GROUND ELEVATION: 339.86 MASL
COREHOLE LOCATION: 12-11-94-8W4	DATE LOGGED: JUNE 11,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (CRDD)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
109.7									
110.4 111.1 111.8 112.6			[illegible] PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), OCC. [illegible] [illegible]	[illegible] TO NODULAR MICRITIC TEXTURES, SOME FINELY INTERBEDDED [illegible] SHALE	SOME KARST SOLUTION FEATURES (PIPES), MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED INCLINED COMPRESSION (?) FRACTURES, FRACTURE AND SOLUTION PIPE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY		N/A
113.2 113.9 114.6 115.3 116.0			[illegible] PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE @ 112.5 m GREY TO OLIVE, FISSILE, WELL CEMENTED (HARD), SOME FAUNA (BRACHIOPODS), SOME PYRITE NODULES	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
116.7 117.4 118.1 118.8 119.5 120.2 120.9 121.6 122.3 123.0 123.7 124.4 125.1			[illegible] PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAINING, SOME KARST COLLAPSE BRECCIA, PYRITE NODULES, SOME FAUNA (BRACHIOPODS)	LAMINAE, SOME FINELY INTERBEDDED LIMESTONE/SHALE	SOME BOUDINAGE, KARST SOLUTION BRECCIA, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID PERMEABILITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 79	GROUND ELEVATION: 358.33 MASL
COREHOLE LOCATION: 12-12-94-5W4	DATE LOGGED: JUNE 12, 1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (DRILLED CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD	
91.7										
92.4 93.1			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY TO OLIVE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	MARBLY TO NODULAR MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/R	
93.8 94.5 95.2 95.9 96.6 97.3 98.0 98.7 99.4 100.1 100.8			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), MODERATELY WEATHERED (DISCOLORED) ALONG DISCONTINUITIES, SOME BITUMEN STAIN	LAMINAE	WEATHERING ALONG DISCONTINUITIES, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/R	
101.5				DISTURBED (BRECCIATED) CALCAREOUS SHALE						
102.2 102.9 103.6 104.3			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/R	
105.0 105.7 106.4			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), MINOR SOLUTION FEATURES, SOME FINELY INTERBEDDED SHALES	MARBLY TO NODULAR MICRITIC TEXTURE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SOLUTION PIPES, FRACTURE AND SOLUTION PIPE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY		N/R	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 80	GROUND ELEVATION: 328.37 MASL
COREHOLE LOCATION: 16-6-94-9W4	DATE LOGGED: SEPTEMBER 15,1981

DEPTH (METRES): 59.6, 60.2, 60.8, 61.4, 62.0, 62.6, 63.2, 63.8, 64.4, 65.0, 65.6, 66.2, 66.8, 67.4, 68.0, 68.6, 69.2, 69.8, 70.4, 71.0, 71.6, 72.2, 72.8, 73.4, 74.0, 74.6, 75.2, 75.8, 76.4, 77.0, 77.6, 78.2, 78.8

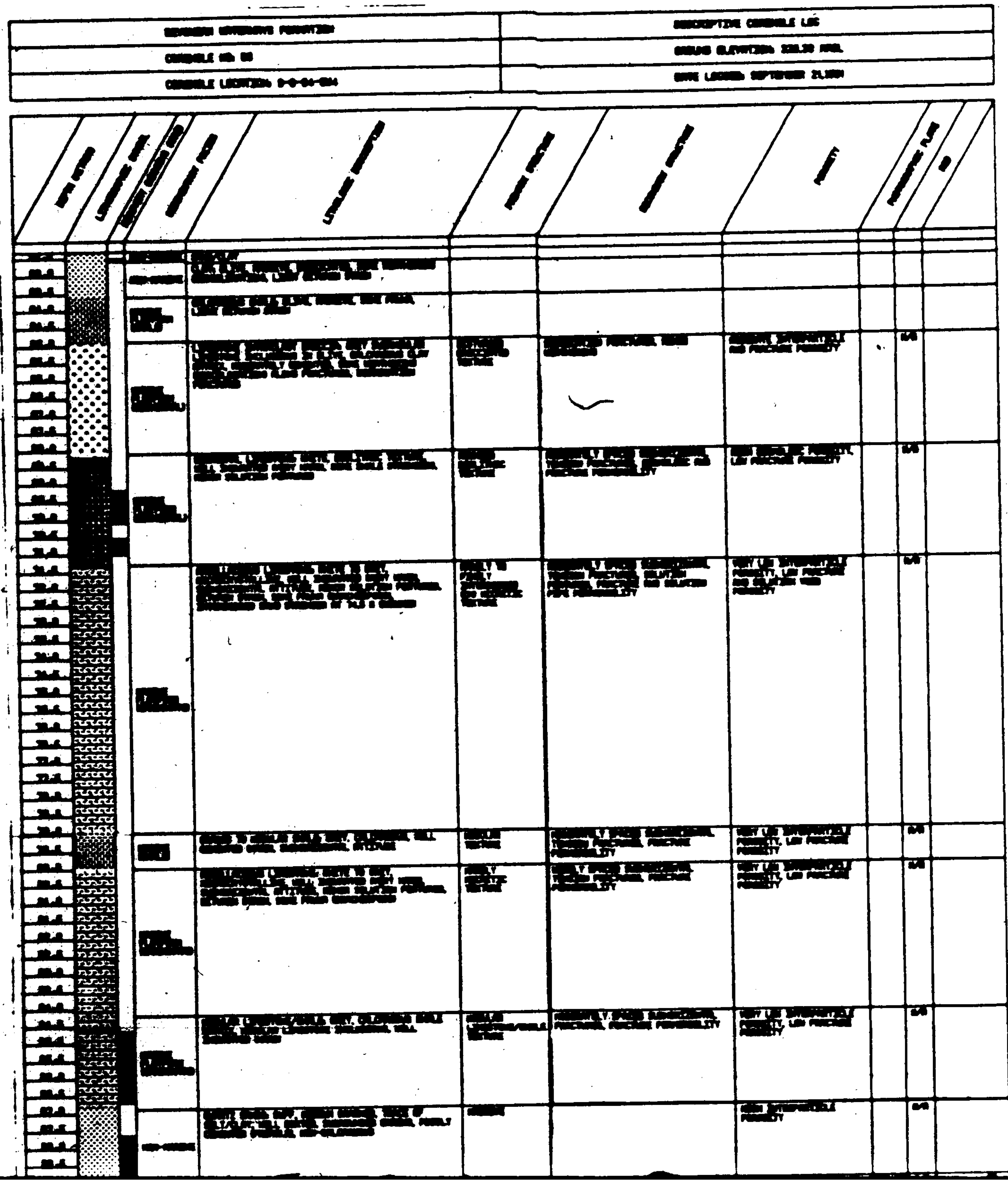
SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD	
NON-MARINE	NON-CALCAREOUS CLAY: OLIVE, DESSICATED, POORLY CEMENTED (FRIABLE)	MASSIVE	CLOSELY SPACED DESSICATION FRACTURES	VERY LOW INTERPARTICLE POROSITY			
NON-MARINE	SAND: LT. BROWN, MEDIUM GRAINED, POORLY CEMENTED (FRIABLE), SOME CLAY MATRIX	MASSIVE		HIGH INTERPARTICLE POROSITY			
NON-MARINE	NON-CALCAREOUS CLAY: OLIVE, DESSICATED, POORLY CEMENTED (FRIABLE)	MASSIVE	CLOSELY SPACED DESSICATION FRACTURES	VERY LOW INTERPARTICLE POROSITY			
NON-MARINE	SAND/CLAY: GREY, DESSICATED	MASSIVE	CLOSELY SPACED DESSICATION FRACTURES	MODERATE INTERPARTICLE POROSITY			
MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA: GREY, SUBANGULAR LIMESTONE INCLUSIONS IN OLIVE, CLAY MATRIX, MODERATELY INDURATED (HARD)	DISTURBED BRECCIATED TEXTURE		MODERATE INTERPARTICLE POROSITY			
	BIOHERMAL LIMESTONE						
	LIMESTONE/CLAY						
MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: WHITE, BIOLITHIC TEXTURE, WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN, SOME RECRYSTALLIZED CALCITE, SOME KARST SOLUTION FEATURES (PIPE)	MOUNDED BIOLITHIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, KARST SOLUTION PIPE, FRACTURE AND SOLUTION PIPE PERMEABILITY	HIGH BIOMOLDIC POROSITY, MODERATE FRACTURE AND SOLUTION POROSITY		N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), SOME KARST SOLUTION FEATURES, MINOR WEATHERING ALONG FRACTURES	MARBLY MICRITIC TEXTURE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME KARST SOLUTION FEATURES (PIPE WITH SAND/CLAY INFILLING), MINOR WEATHERING, FRACTURE AND SOLUTION PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
NON-MARINE	SAND/CLAY						
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA	MARBLY MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
MARINE PLATFORM (CARBONATE)	INTERBEDDED LIMESTONE/SHALE: GREY, WELL INDURATED (HARD), SUBHORIZONTAL ATTITUDE	FINELY INTERBEDDED LIMESTONE/SHALE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, EXTENSIVE BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 84	GROUND ELEVATION: 335.99 MASL
COREHOLE LOCATION: 14-30-94-8W4	DATE LOGGED: JUNE 18,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
68.7, 69.4, 70.1, 70.8, 71.5, 72.2, 72.9, 73.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: OLIVE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE, ABUNDANT FAUNA (BRACHIOPODS), SOME SOLUTION FEATURES	NODULAR TO FINELY INTERBEDDED (2) LIMESTONE/SHALE	WIDELY SPACED SUBHORIZONTAL/SUBVERTICAL FRACTURES, SOME SOLUTION FEATURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
74.3, 75.0, 75.7, 76.4, 77.1, 77.8, 78.5, 79.2, 79.9, 80.6, 81.3, 82.0, 82.7, 83.4, 84.1			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, SOME ANGULAR INTRACLASTS, MINOR WEATHERING (DISCOLOURATION) ALONG FRACTURES, SEVERAL HARD BIOSPARITIC ZONES	LAMINAE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, MINOR WEATHERING, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 86	GROUND ELEVATION: 332.85 MASL
COREHOLE LOCATION: 5-5-94-5W4	DATE LOGGED: JULY 7,1981

DEPTH METRES	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
60.5 – 62.0	MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA: GREY SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS CLAY MATRIX, SOME INTERBEDDED BITUMINOUS SANDS, HIGHLY DESSICATED, SOME WEATHERING DISCOLORATION, BITUMEN STAIN	SOME LAMINAE, SUBTLE BEDDING	CLOSELY SPACED RANDOM FRACTURES	LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
62.0 – 63.0	MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE, GREY, BIOLITHIC TEXTURE, WELL INDURATED (HARD), EXTENSIVE SOLUTION (VERTICAL PIPE INFILLED WITH LT. GREEN CLAY), HEAVY BITUMEN STAIN	MOUNDED BIOLITHIC TEXTURE	SOME SOLUTION FEATURES, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
63.0 – 66.5	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), SOME SAND	FINELY INTERBEDDED (CM) SHALE/LIMESTONE, SOME NODULAR TEXTURES	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
66.5 – 67.5	MARINE (BIOHERMAL)	BIOHERMAL LIMESTONE, GREY, BIOLITHIC TEXTURE, WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
67.5 – 68.0	MARINE (CARBONATE)	ARGILLACEOUS LIMESTONE, GREY, MICROCRYSTALLINE, WELL INDURATED, SUBHORIZONTAL ATTITUDE	MARBLY MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
68.0 – 70.0	MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE, GREY, BIOLITHIC TEXTURE, WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
70.5 – 73.0	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME BIOSPARITIC ZONES, SOME FAUNA (BRACHIOPODS), MINOR WEATHERING (DISCOLORATION ALONG FRACTURES), BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (CM) SHALE/LIMESTONE	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
73.0 – 82.0	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, HIGH MICRITE CONTENT, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA (BRACHIOPODS)	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE, SOME SHALY ZONES, OLIVE CLAY AT CONTACT (72.8 M)	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND BIOMOLDIC POROSITY	N/A	



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DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 88	GROUND ELEVATION: 328.5 MASL
COREHOLE LOCATION: 15-8-94-5W4	DATE LOGGED: JUNE 11,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (CORING CARD)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
58.7 – 66.4			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA (BRACHIOPODS)	MARBLY TO FINELY INTERBEDDED (C/M) MICRITIC TEXTURE	SOME BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL AND SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND BIOMOLDIC POROSITY		N/A	
67.1 – 68.5			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY TO OLIVE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS)	LAMINAR TO NODULAR TEXTURE, BLOCKY TEXTURE AT 68-M	WIDELY SPACED SUBVERTICAL AND SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	
69.2 – 76.2			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS)	MARBLY TO FINELY INTERBEDDED (C/M) MICRITIC TEXTURES	SOME BOUDINAGE, WIDELY SPACED SUBVERTICAL AND SUBHORIZONTAL FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	

Depth scale (metres): 58.7, 59.4, 60.1, 60.8, 61.5, 62.2, 62.9, 63.6, 64.3, 65.0, 65.7, 66.4, 67.1, 67.8, 68.5, 69.2, 69.9, 70.6, 71.3, 72.0, 72.7, 73.4, 74.1, 74.8, 75.5, 76.2

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 98	GROUND ELEVATION: 326.43 MASL
COREHOLE LOCATION: 1-7-94-9W4	DATE LOGGED: JULY 27,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (POSSIBLE CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
56.7 57.4 58.1 58.8 59.5 60.2 60.9 61.6			MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA: WHITE TO GREY, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS CLAY/SAND MATRIX, HEAVY BITUMEN STAIN	DISTURBED BRECCIATED STRUCTURE, HOMOGENEOUS	WIDELY SPACED DESSICATION FRACTURES	MODERATE INTERPARTICLE POROSITY	1003 841	
62.3 63.0			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: WHITE, BIOLITHIC TEXTURE, WELL INDURATED (HARD), SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN, UNDISTURBED	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, BIOMOLDIC AND FRACTURE PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
63.7 64.4 65.1 65.8 66.5 67.2 67.9 68.6 69.3 70.0 70.7 71.4 72.1 72.8 73.5 74.2 74.9 75.6 76.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), LIGHT BITUMEN STAIN, SHALY BELOW 73 M	MARLY TO FINELY INTERBEDDED (2) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	986 798 745 853 713	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 9I	GROUND ELEVATION: 325.29 MASL
COREHOLE LOCATION: 3-7-94-9W4	DATE LOGGED: JULY 23,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	SEDIMENT REGIME CODE	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
[illegible]			MARINE PLATFORM CARBONATE	ARGILLACEOUS LIMESTONE, WHITE, MICROCRYSTALLINE, WELL [illegible], SUBHORIZONTAL ATTITUDE, SOME [illegible], BITUMEN STAIN, [illegible] SOLUTION FEATURES, SOME FRAGM. ECC. [illegible] ZONE, HIGHLY ARGILLACEOUS BELOW 94.5 M	NODULY NODULITIC TEXTURE, FINELY INTERBEDDED SHALE/LIMESTONE BELOW 97 M	SOLUTION FEATURES IN UPPER 2.4 M, WIDELY SPACED RANDOM FRACTURES, SOME BOUDINAGE, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY		[illegible]	
[illegible]			MARINE PLATFORM SHALE	[illegible] TO CALCAREOUS SHALE BELOW 89.8 M GREY, FISSILE, WELL CEMENTED [illegible], SUBHORIZONTAL ATTITUDE, SOME [illegible]	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	
[illegible]			MARINE PLATFORM CARBONATE	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, FINELY INTERBEDDED TO 96.1 M, WELL [illegible], SUBHORIZONTAL ATTITUDE, HIGHLY ARGILLACEOUS BELOW 97 M, GRADES TO CALCAREOUS SHALE AT 98 M GREY, FISSILE, WELL CEMENTED	FINELY INTERBEDDED TO LAMINAR SHALES	SOME BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 92	GROUND ELEVATION: 325.60 MASL
COREHOLE LOCATION: 9-7-94-9W4	DATE LOGGED: JULY 23,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (BROKEN CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
69.6										
70.2 – 76.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, ABUNDANT FAUNA (BRACHIOPODS), MINOR SOLUTION FEATURES, MINOR WEATHERING ALONG FRACTURES, WELL DEFINED BEDDING BELOW 74 M	MAINLY MICRITIC TO FINELY INTERBEDDED SHALE/LIMESTONE	EXTENSIVE BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL/RANDOM FRACTURES, FRACTURE PERMEABILITY, MINOR SOLUTION EFFECTS	LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY		048, 238, 06, 08, 086	
77.4 – 78.0			MARINE SHALE	GRADES TO CALCAREOUS SHALE; OLIVE TO GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS, SOME PYRITE	LAMINAE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS	BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		045	
78.6 – 81.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, BITUMEN STAIN, SOME PYRITE, RECRYSTALLIZED CALCITE	MAINLY TO FINELY INTERBEDDED (CM) SHALE/LIMESTONE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY, SOME BOUDINAGE	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
82.2 – 83.4			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME FINELY INTERBEDDED LIMESTONE, SOME PYRITE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 93	GROUND ELEVATION: 325.94 MASL
COREHOLE LOCATION: 15-7-94-9W4	DATE LOGGED: AUGUST 13,1981

Depth (metres) scale: 72.2, 72.8, 73.4, 74.0, 74.6, 75.2, 75.8, 76.4, 77.0, 77.6, 78.2, 78.8, 79.4, 80.0, 80.6, 81.2, 81.8, 82.4, 83.0, 83.6, 84.2, 84.8, 85.4, 86.0, 86.6, 87.2, 87.8, 88.4, 89.0, 89.6, 90.2, 90.8

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
[illegible] (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN, WEATHERING DISCOLORATION IN UPPER 0.4 M, SOME SOLUTION FEATURES	MARBLY MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SOLUTION FEATURES, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY		N/A
[illegible] (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOLUTION FEATURES AT 76 M (POTENTIAL INTRAFORMATIONAL UNCONFORMITY)	MARBLY TO FINELY INTERBEDDED W/ MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, SOME SOLUTION FEATURES (PIPES), FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY		N/A
NON-MARINE	QUARTZ SAND: BK. BROWN, MEDIUM GRAINED, SOME SILT/CLAY, BITUMEN STAIN, POORLY CEMENTED (FRIABLE), SOME DETRITAL LIMESTONE/SHALE	MASSIVE		HIGH INTERPARTICLE POROSITY		N/A
[illegible] (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MARBLY TO FINELY INTERBEDDED W/ MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
[illegible] (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, MINOR WEATHERING DISCOLORATION, BITUMEN STAIN	NODULAR TO FINELY INTERBEDDED TEXTURE, SOME LAMINAE	SOME BOUDINAGE, WEATHERING, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
[illegible] (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	FINELY INTERBEDDED W/ LIMESTONE/SHALE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 94	GROUND ELEVATION: 325.5 MASL
COREHOLE LOCATION: JUNE 11,1981	DATE LOGGED: 3-8-94-9W4

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (ROCKING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
82.7 83.4 84.1 84.8 85.5 86.2 86.9 87.6 88.3 89.0 89.7 90.4 91.1 91.8 92.5 93.2 93.9 94.6 95.3 96.0			[illegible]	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, OCC. PYRITE NODULE, NUMEROUS [illegible] ZONES, BITUMEN STAIN, WEATHERED DISCOLOURED UPPER 30 CM, BRECCIATED ZONE AT 82.95 M	FAINTLY TO FINELY INTERBEDDED W/ MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, BOUDINAGE PROMINENT AT 50-60 M, BRECCIATED ZONE 82.95 M - POTENTIAL SHEAR ZONE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	
96.7 97.4 98.1 98.8 [illegible]			[illegible]	GRADES TO CALCAREOUS SHALE; OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 95	GROUND ELEVATION: 325.94 MASL
COREHOLE LOCATION: 5-9-94-9W4	DATE LOGGED: JULY 7,1981

DEPTH METRES
53.6
54.2
54.8
55.4
56.0
56.6
57.2
57.8
58.4
59.0
59.6
60.2
60.8
61.4
62.0
62.6
63.2
63.8
64.4
65.0
65.6
66.2
66.8
67.4
68.0
68.6
69.2

LITHOGRAPHIC SYMBOL	RECOVERY (CORING CARD)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
		MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, MINOR WEATHERING (DISCOLOURATION), SOME SANDY HORIZONS, OCC. PYRITE NODULE, GRADES TO CALCAREOUS SHALE BELOW 59M	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, MINOR WEATHERING, SOME BOUDINAGE. FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
		MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE: OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, OCC. BIOSPARITIC ZONE, SOME PYRITE	LAMINAE, SOME FINELY INTERBEDDED (CM) LIMESTONE/SHALE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL FRACTURE, SOME BOUDINAGE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
		MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, HIGH BIOLITHIC CONTENT, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN IN SUBVERTICAL FRACTURES	FINELY INTERBEDDED SHALE/LIMESTONE, SOME PACKSTONE TEXTURES	EXTENSIVE BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL FRACTURES, WIDELY SPACED SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 97	GROUND ELEVATION: 325.58 MASL
COREHOLE LOCATION: 11-8-94-9W4	DATE LOGGED: AUGUST 19,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (MISSING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
53.7 54.4			NON-MARINE	CLAY: GREY, NON-CALCAREOUS, LAMINATED, WELL CEMENTED (HARD), SOME BITUMINOUS SAND STRINGERS, STEEPLY DIPPING (< 35°)	INTERBEDDED SAND STRINGERS	DESSICATION FRACTURES	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
55.1 55.8 56.5 57.2 57.9 58.6			MARINE (PLATFORM CARBONATE)	ARGILLACEOUS LIMESTONE GRADES TO CALCAREOUS SHALE BELOW 57 m WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	FINELY INTERBEDDED LIMESTONE/SHALE GRADES TO FISSILE SHALE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
59.3 60.0			[illegible]	BIOHERMAL LIMESTONE: GREY TO BUFF, WELL INDURATED (HARD), HEAVY BITUMEN STAIN, SOME RECRYSTALLIZED CALCITE	MOUNDED, BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		--- --- 70%
60.7 61.4 62.1			MARINE (PLATFORM CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HIGH MICRITE CONTENT, HEAVY BITUMEN STAIN, SOME FAUNA (BRACHIOPODS), PYRITE, SOME SOLUTION FEATURES	MARBLY TO FINELY INTERBEDDED TEXTURE	BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOLUTION FEATURES, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		--- --- --- 50%
62.8 63.5			NON-MARINE	BITUMINOUS SAND: MEDIUM GRAINED, HIGH CLAY CONTENT, HEAVY BITUMEN SATURATION	MASSIVE				
64.2 64.9 65.6 66.3 67.0 67.7 68.4 69.1			MARINE (PLATFORM CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, HIGH MICRITE CONTENT, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, ABUNDANT FAUNA (BRACHIOPODS), PYRITE	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		--- --- --- 75% --- --- --- 45%
69.8			MARINE (SHALE)	GRADES TO CALCAREOUS SHALE BELOW 68 m GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE, SOME NODULAR TEXTURES	SOME BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		--- --- 30%
70.5 71.2 71.9 72.6 73.3 74.0			MARINE (PLATFORM CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
74.7 75.4			MARINE (SHALE)	GRADES TO CALCAREOUS SHALE BELOW 74 m GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE, SOME NODULAR TEXTURES	[illegible]LY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 98	GROUND ELEVATION 334.9 MASL
COREHOLE LOCATION 5-10-94-9W4	DATE LOGGED JUNE 11,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (CORING CODE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
133.7									
134.4 135.1			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A
135.8 136.5			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), PYRITIC, VERTICAL SOLUTION PIPE WITH OLIVE CLAY INFILLING	NODULAR MICRITIC TEXTURE	EXTENSIVE KARST SOLUTION, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY		N/A
137.2 137.9 138.6 139.3 140.0 140.7 141.4 142.1 142.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS)	MARBLY TO NODULAR MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, KARST SOLUTION FEATURES (PIPE), FRACTURE AND SOLUTION PIPE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY		N/A
143.5 144.2 144.9 145.6 146.3 147.0			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE; OLIVE, FISSILE, WELL CEMENTED (HARD), SOME PYRITE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL COMPRESSION (?) FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
147.7 148.4 149.1			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE, POTENTIAL HARDGROUND AT 148.4 M	FINELY INTERBEDDED (CM) SHALE/LIMESTONE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A
149.8 150.5 151.2 151.9 152.6 153.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A

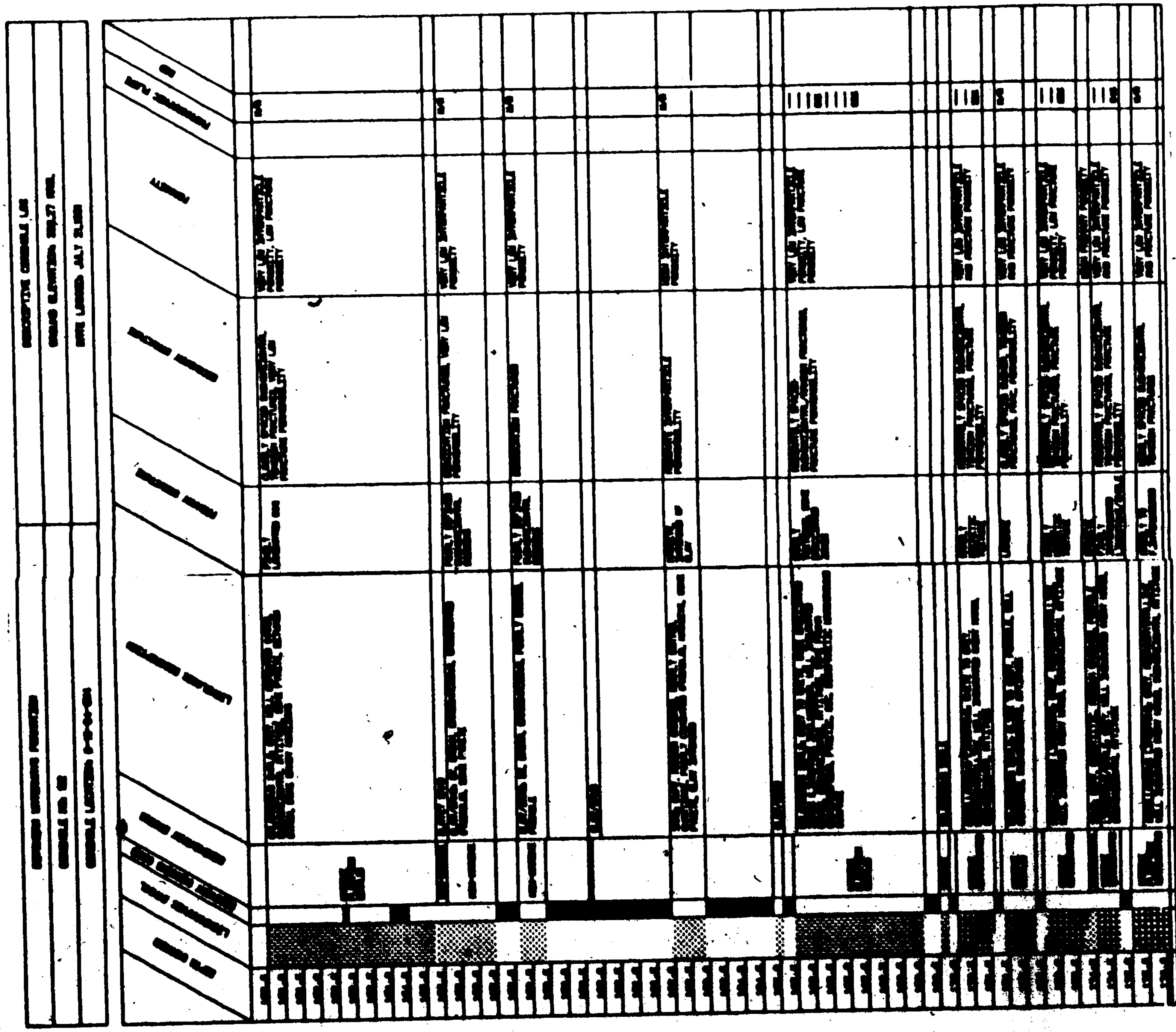
DEVONIAN [illegible]WAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: [illegible]	GROUND ELEVATION: 338.93 MASL
COREHOLE LOCATION: 14-14-84-9W4	DATE LOGGED: JULY 16,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY FOOTAGE CORED	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
[illegible], 87.5, 88.3, [illegible]			MARINE PLATFORM SHALE	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME BITUMEN STAIN, OCC. PYRITE NODULE	LAMINAE, SOME LIMESTONE NODULES	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL COMPRESSION (?) FRACTURE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
[illegible], [illegible], 91.3, [illegible], [illegible], [illegible], 94.3, [illegible], [illegible], [illegible], 97.3			MARINE PLATFORM CARBONATE	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), SOME BITUMEN STAIN, SOME SOLUTION FEATURES (SUBVERTICAL PIPE INFILLED WITH LT. GREEN CLAY AT 92 M), SOME PYRITE	NODULY TEXTURE, POORLY DEFINED BEDDING	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOLUTION FEATURES, FRACTURE AND SOLUTION PIPE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY		381, 341, 836, 915, 738	
[illegible], [illegible], [illegible], 100.3, 101.[illegible], 101.[illegible]			MARINE PLATFORM SHALE	GRADES TO CALCAREOUS SHALE: GREY, FISSILE, SOME INTERBEDDED LIMESTONE NODULES, WELL CEMENTED (VERY HARD), ABUNDANT FAUNA (BRACHIOPODS), SUBHORIZONTALLY ALIGNED PYRITE NODULES	LAMINAE, ELONGATE PYRITE NODULES	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL COMPRESSION (?) FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		888, 351	
102.5, 103.3, 104.[illegible], 104.[illegible], [illegible]			[illegible]	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, FINELY INTERBEDDED MICRITE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS)	NODULY TO FINELY INTERBEDDED TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, LOW FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 101	GROUND ELEVATION: 326.70 MASL
COREHOLE LOCATION: 14-15-94-5W4	DATE LOGGED: JULY 20,1981

Depth (metres): 111.5, 112.0, 112.5, 113.0, 113.5, 114.0, 114.5, 115.0, 115.5, 116.0, 116.5, 117.0, 117.5, 118.0, 118.5, 119.0, 119.5, 120.0, 120.5, 121.0, 121.5, 122.0, 122.5, 123.0, 123.5, 124.0, 124.5, 125.0, 125.5, 126.0, 126.5, 127.0, 127.5, 128.0, 128.5, 129.0, 129.5, 130.0

Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), SOME PYRITE, WEATHERING DISCOLORATIONS IN UPPER 0.2	MARBLY TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND SOLUTION CHANNEL PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY	723 586	
	QUARTZ SAND: BUFF, POORLY CEMENTED (FRIABLE), MEDIUM GRAINED	TRACE OF BEDDING	CLEAN, PERMEABLE	MODERATE TO HIGH INTERPARTICLE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACIOPODS)	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, LOW FRACTURE PERMEABILITY.	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	708 730 575	
MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE BELOW 119 m: GREY, FISSILE, WELL CEMENTED (VERY HARD), SOME FAUNA (BRACHIOPODS), PYRITE NODULES ALONG FRACTURES FINELY INTERBEDDED CLAY/LIMESTONE AT 125 m (SUBHORIZONTAL)	LAMINAE, INTERBEDDED CLAY/LIMESTONE, MARBLY TEXTURE BELOW 120	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE AT 125 m, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	586	
MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (VERY HARD), ABUNDANT FAUNA (BRACHIOPODS)	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	



DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 104	GROUND ELEVATION: 325.67 MASL
COREHOLE LOCATION: 5-17-94-SW4	DATE LOGGED: JULY 8,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (FOOTAGE CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
[illegible] – [illegible]			MARINE PLATFORM (CARBONATE)	DISTURBED CALCAREOUS SHALE/LIMESTONE; WHITE TO GREY, FINELY INTERBEDDED (CM), LIGHT BITUMEN STAIN, ICE, BIOSPARITIC ZONE, SOME PYRITE, MINOR BRECCIATION (FRAGMENTATION)	FINELY INTERBEDDED (CM) SHALE/LIMESTONE, PLASTICALLY DEFORMED CLAYS	DISTURBED (SLUMPED) APPEARANCE, STEEPLY DIPPING BEDS > 20 DEGREES, CLOSELY SPACED FRACTURES (SUBPARALLEL TO BEDDING), SOME BOUDINAGE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 105	GROUND ELEVATION: 324.35 MASL
COREHOLE LOCATION: 7-17-94-5W4	DATE LOGGED: JULY 21,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (RECORDING CORE)	SEDIMENTARY PHASES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
60.0 60.7 61.4 62.1 62.8 63.5			MARINE PLATFORM CARBONATE	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME BITUMEN STAIN, OCC. PYRITE NODULE, ABUNDANT FAUNA (BRACHIOPODS), SOME SANDY INTERBEDS	MARBLY TEXTURE, SOME FINELY INTERBEDDED MICRITE, SOME SANDY BEDS	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED RANDOM FRACTURES, SOME DISTURBED BEDDING, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	515	
64.2 64.9 65.6 66.3 67.0 67.7 68.4 69.1 69.8 70.5 71.2 71.9 72.6 73.3 74.0 74.7 75.4			MARINE PLATFORM SHALE	GRADES TO CALCAREOUS SHALE BELOW 63.5 m GREY TO OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, OCC. PYRITE NODULE, HIGHLY ARGILLACEOUS BELOW 71	MARBLY TO LAMINAR TEXTURE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS	SOME BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 186	GROUND ELEVATION: 325.27 MASL
COREHOLE LOCATION: 9-17-94-9W4	DATE LOGGED: AUGUST 11,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (MISSING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
[illegible] – 81.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN, DISTURBED APPEARANCE	MARBLY TO FINELY INTERBEDDED [illegible] TEXTURE	MODERATELY SPACED RANDOM FRACTURES, DISTURBED FRACTURE PATTERN, SOME BOUDINAGE	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY		N/A
82.0 – [illegible]			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, GREY, FISSILE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, MINOR SOLUTION FEATURES, TRACE OF BITUMEN STAIN	LAMINAR TO FINELY INTERBEDDED TEXTURE	EXTENSIVE BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, MINOR SOLUTION FEATURES (PIPES) WITH ASSOCIATED BRECCIA	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: W7	GROUND ELEVATION: 325.06 MASL
COREHOLE LOCATION: 13-17-94-9W4	DATE LOGGED: JULY 15, 1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (BOXING CODE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
73.5 – 76.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, MINOR WEATHERING	MAINLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	606	
76.0 – … 88.5			MARINE PLATFORM (CARBONATE)	CALCAREOUS SHALE, OLIVE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME NODULAR LIMESTONE STRINGERS, SOME FAUNA (BRACHIOPODS), OCC. [illegible], SOME PYRITE, GRADES TO FINELY INTERBEDDED SHALE/LIMESTONE BELOW 79M	LAMINAE, SOME FINELY INTERBEDDED C/O LIMESTONE STRINGERS	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, POTENTIAL SOLUTION FEATURE AT 81.1	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	580, 606, 718, 565	

Depth marks (m): 73.5, 74.0, 74.5, 75.0, 75.5, 76.0, 76.5, 77.0, 77.5, 78.0, 78.5, 79.0, 79.5, 80.0, 80.5, 81.0, 81.5, 82.0, 82.5, 83.0, 83.5, 84.0, 84.5, 85.0, 85.5, 86.0, 86.5, 87.0, 87.5, 88.0, 88.5

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 100	GROUND ELEVATION: 325.54 MASL
COREHOLE LOCATION: 1-10-94-5W4	DATE LOGGED: AUGUST 21,1981

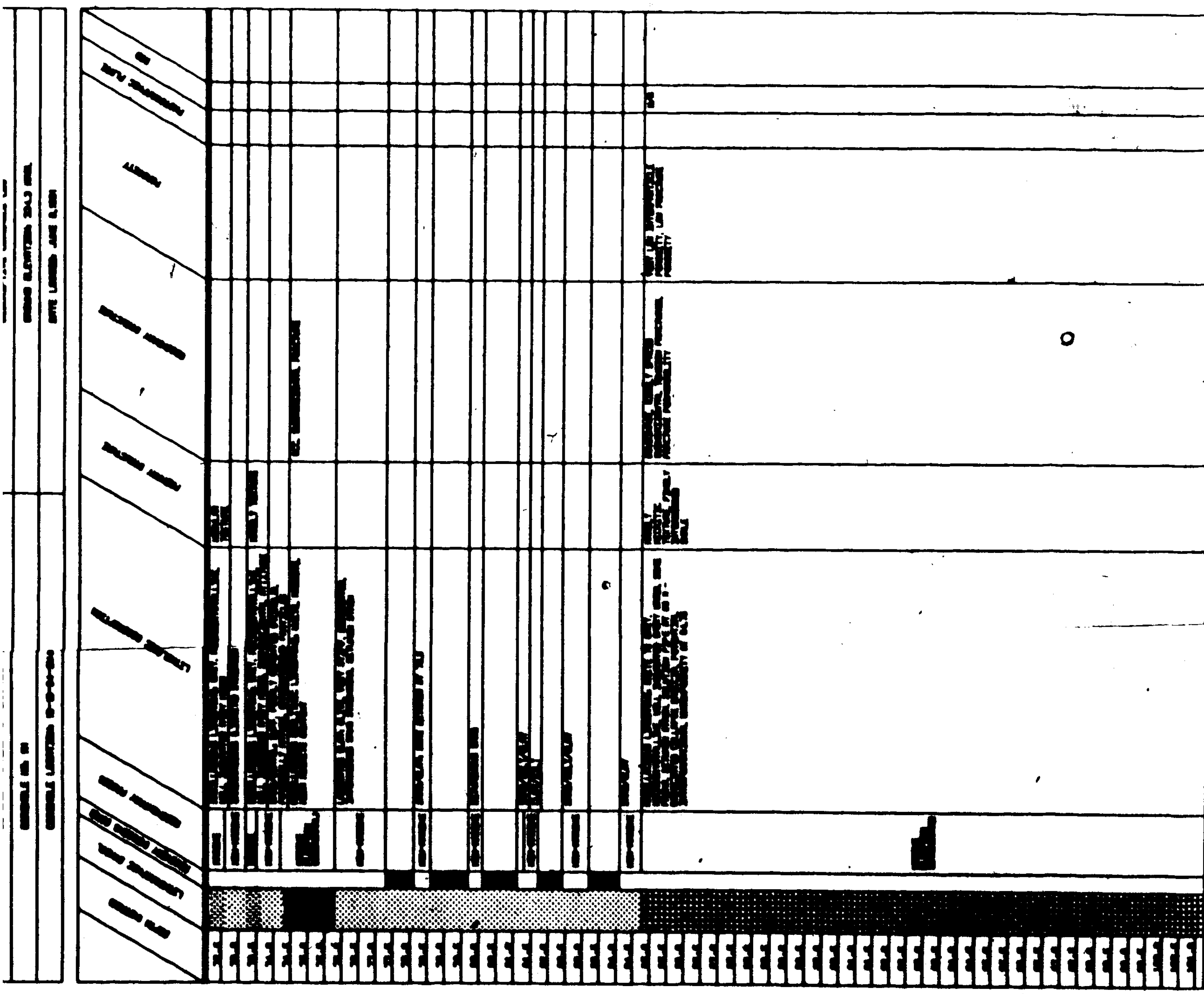
DEPTH METRES	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
59.7, 60.4	NON-MARINE	CLAY SHALE; OLIVE, WEATHERED (DISCOLORED), WELL CEMENTED (NON-CALCAREOUS), SUBTLE FISSILITY	POORLY DEFINED LAMINAE	WEATHERED OXIDATION STAIN, DESICCATION FRACTURES			
61.1, 61.8, 62.5, 63.2	MARINE PLATFORM ([illegible])	LIMESTONE INTRACLAST BRECCIA; GREY, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS SHALE MATRIX, MODERATELY WELL INDURATED, SOME FAUNA	DISTURBED BRECCIATED TEXTURE, DESICCATION FRACTURES	WIDELY SPACED DESICCATION FRACTURES	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	[illegible], [illegible]	
63.9, 64.6, 65.3, 66.0, 66.7	MARINE PLATFORM ([illegible])	[illegible] LIMESTONE; WHITE, WELL INDURATED (HARD), HEAVY BITUMEN STAIN, EXTENSIVE SOLUTION (PIPE INFILLED WITH LT. GREEN SIDERITIC CLAY), ABUNDANT FAUNA	[illegible] BIOLITHIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOLUTION PIPES, FRACTURE AND SOLUTION PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY	[illegible]	
67.4, 68.1, 68.8, 69.5, 70.2, 70.9, 71.6, 72.3, 73.0, 73.7, 74.4, 75.1, 75.8, 76.5, 77.2	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA, HEAVY BITUMEN STAIN, EXTENSIVE SOLUTION (PIPE INFILLED WITH LT. GREEN CLAY, SOME SIDERITE), ABUNDANT FAUNA	NODULY TEXTURE, SOME FINELY INTERBEDDED MICRITE, WELL DEFINED BEDDING BELOW 74 M	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED RANDOM FRACTURES, SOME BOUDINAGE, SOLUTION PIPES, SOME COLLAPSE BRECCIA AT 72 M, UNDISTURBED BELOW 74 M, VERTICAL PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE SOLUTION VOID AND FRACTURE POROSITY	776, [illegible], [illegible]	
77.9, 78.6, 79.3, [illegible]	MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAR/NODULAR TEXTURE, SOME F. INTERBEDDED LIMESTONE STRINGERS	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 109	GROUND ELEVATION: 325.58 MASL
COREHOLE LOCATION: 3-10-94-8W4	DATE LOGGED: SEPTEMBER 10,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY PERIODS (CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
[illegible]			MARINE PLATFORM ([illegible])	[illegible] LIMESTONE: WHITE, OOLITHIC TEXTURE, WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN, SOME INTERBEDDED MICRITIC ZONES, ABUNDANT FAUNA, MINOR RECRYSTALLIZATION	ROUNDED OOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL/RANDOM FRACTURES	HIGH ECONOLOGIC POROSITY, LOW FRACTURE POROSITY	871	
[illegible]			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, LIGHT BITUMEN STAIN, SOME SOLUTION COLLAPSE FEATURES (SLUMPED BEDDING, INFILLED PIPE, CARBONACEOUS PARTICLES)	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY, SOLUTION FEATURES (PIPE INFILLED WITH COLLAPSE BRECCIA), SOME BOUDINAGE	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	726	
[illegible]			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, LIGHT BITUMEN STAIN, POTENTIAL HARDGROUND SURFACE AT 81.1-81.3 M	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	771, 806	
[illegible]			MARINE SHALE(S)	GRADES TO CALCAREOUS SHALE: GREY, FISSILE, MODERATELY CEMENTED (FRIABLE), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS)	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
[illegible]			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	806, 951	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 1B	GROUND ELEVATION: 326.3 MASL
COREHOLE LOCATION: 7-18-94-5W4	DATE LOGGED: JULY 28,1981

DEPTH METRED	LITHOGRAPHIC SYMBOL	RECOVERY (MISSING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
73.5 74.0 74.5 75.0 75.5 76.0 76.5			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	MARBLY MICRITIC TEXTURE, SOME FINELY INTERBEDDED (CM) SHALE/LIMESTONE, SOME LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, RANDOM FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
77.0 77.5			MARINE SHALE	GRADES TO CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
78.0 78.5 79.0 79.5 80.0 80.5			MARINE PLATFORM (CARBONATE)	GRADES TO ARGILLACEOUS LIMESTONE; WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	FINELY INTERBEDDED SHALE/LIMESTONE, SOME MARBLY TO LAMINAR TEXTURES	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
81.0 81.5 82.0 82.5 83.0 83.5 84.0 84.5 85.0 85.5 86.0 86.5 87.0 87.5 88.0 88.5 89.0 89.5			MARINE PLATFORM (SHALE)	GRADES TO NODULAR SHALE/LIMESTONE; GREY, POORLY DEFINED LIMESTONE NODULES IN CALCAREOUS CLAY MATRIX, SUBHORIZONTAL NODULE ELONGATION, OOLITHIC ZONE AT 83.1 M, BITUMEN STAINED, SHALY AT 88 M	NODULAR TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME RANDOMLY ORIENTED FRACTURES (ABOUT NODULES), POORLY DEVELOPED BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	



DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 112	GROUND ELEVATION: 324.86 MASL
COREHOLE LOCATION: 15-10-94-5W4	DATE LOGGED: JULY 15, 1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
50.7										
51.4				ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, FINELY INTERBEDDED SHALE, WEATHERED UPPER CONTACT, SOME BITUMEN STAIN, OCC. PYRITE NODULE, OCC. BIOSPARITIC HARDGROUND	MARBLY TO FINELY INTERBEDDED ICM TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, EXTENSIVE BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
52.1										
52.8										
53.5			MARINE PLATFORM (CARBONATE)							
54.2										
54.9										
55.6										
56.3										
57.0				FINELY INTERBEDDED BELOW 57 M, POTENTIAL HARDGROUND SURFACE AT 58 M (SPARITIC)						
57.7										
58.4										
59.1										
59.8										
60.5				HIGHLY ARGILLACEOUS BELOW 60 M: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, UNIFORM GRAIN SIZE, UNDISTURBED, FINELY INTERBEDDED ICM BELOW 63 M, POTENTIAL HARDGROUND AT 66 M	LAMINAE, FINELY INTERBEDDED ICM	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
61.2										
61.9										
62.6										
63.3										
64.0			MARINE PLATFORM (SHALE)							
64.7										
65.4										
66.1										
66.8										
67.5										

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 114	GROUND ELEVATION: 324.22 MASL
COREHOLE LOCATION: 7-19-94-9W4	DATE LOGGED: SEPTEMBER 4,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (DRILLING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
[illegible]			NON-MARINE	NON-CALCAREOUS CLAY: OLIVE, DESSICATED, FRIABLE					
60.5 61.3 62.0 62.8 63.5 64.3 65.0 65.8			MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA: WHITE TO GREY, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS CLAY MATRIX, SIDERITE RIMS ABOUT INCLUSIONS, SOME WEATHERING DISCOLORATION	DISTURBED, BRECCIATED TEXTURE	DESSICATION FRACTURES, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	MODERATE INTERPARTICLE POROSITY	N/A	
66.5 67.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MARBLY MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	[illegible] --- --- [illegible]	
68.0 68.8 69.5 70.3			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: WHITE, BIOLITHIC TEXTURE, WELL INDURATED, HEAVY BITUMEN STAIN, SOME SOLUTION FEATURES, ABUNDANT FAUNA	MOUNDED BIOLITHIC TEXTURE	MINOR SOLUTION FEATURES, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, BIOMOLDIC AND FRACTURE PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	--- --- --- [illegible]	
71.0			[illegible]	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE	MARBLY				
71.8			[illegible]	BIOHERMAL LIMESTONE: WHITE, WELL INDURATED, BITUMEN STAIN, MOUNDED	BIOLITHIC TEXTURE		HIGH BIOMOLDIC POROSITY		
72.5 73.3 74.0 74.8 75.5 76.3 77.0 77.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, LIGHT BITUMEN STAIN, SOLUTION COLLAPSE ZONE AT 73.4 M, HIGHLY ARGILLACEOUS BELOW 77.8 M	MARBLY MICRITIC TEXTURE	SOLUTION COLLAPSE FEATURES, SUBVERTICAL PIPE INFILLED WITH OLIVE CLAY/LIMESTONE FRAGMENTS, SOME BOUDINAGE, WIDELY SPACED FRACTURES	LOW INTERPARTICLE AND FRACTURE POROSITY, MODERATE SOLUTION POROSITY	--- --- --- 925	
78.5 79.3 80.0 80.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	--- --- --- 315 --- --- --- 738	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 1[illegible]	GROUND ELEVATION: 323.82 MASL
COREHOLE LOCATION: 15-19-94-W4	DATE LOGGED: JULY 14,1981

Depth (metres): 60.1, 60.7, 61.3, 61.8, 62.5, 63.1, 63.7, 64.3, 64.8, 65.5, 66.1, 66.7, 67.3, 67.8, 68.5, 69.1, 69.7, 70.3, 70.8, 71.5, 72.1, 72.7, 73.3, 73.8, 74.5, 75.1

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA: GREY, SUBANGULAR LIMESTONE INCLUSIONS IN OLIVE CLAY/SAND MATRIX, UPPER 1 M WEATHERED (DISCOLORED), DISTURBED BEDDING, EXTENSIVE SOLUTION FEATURES, SOME FAUNA [illegible]	DISTURBED SLUMPED BEDDING, BRECCIATED TEXTURE	MODERATELY SPACED RANDOM FRACTURES, FRACTURE AND SOLUTION PIPE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION POROSITY	[illegible], [illegible]	
MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: BUFF TO BROWN, HIGH MICRITE CONTENT, EXTENSIVE WEATHERING AND SOLUTION FEATURES, HEAVY BITUMEN STAIN, SOLUTION CAVITIES INFILLED WITH LT. GREEN CLAY	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, EXTENSIVE KARST SOLUTION FEATURES, FRACTURE AND SOLUTION PIPE PERMEABILITY	HIGH [illegible], FRACTURE AND SOLUTION VOID POROSITY	[illegible]	
MARINE PLATFORM (CARBONATE)	WEATHERED BIOHERMAL LIMESTONE GRADES TO ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, NO SOLUTION FEATURES BELOW 7[illegible]	FINELY INTERBEDDED LIMESTONE AND SHALE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY, SOLUTION PIPE INFILLED WITH LT. GREEN PLASTIC CLAY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	[illegible]	

DEVONIAN WATERWAYS FORMATION

COREHOLE NO: 117

COREHOLE LOCATION: 5-20-94-9W4

DESCRIPTIVE COREHOLE LOG

GROUND ELEVATION: 323.10 MASL

DATE LOGGED: JULY 6,1981

Depth (metres): [illegible], 69.5, 70.0, 70.5, 71.0, 71.5, 72.0, 72.5, 73.0, 73.5, 74.0, 74.5, 75.0, 75.5, 76.0, 76.5, 77.0, 77.5, 78.0, 78.5, 79.0, 79.5, 80.0, 80.5, 81.0, 81.5, 82.0, 82.5, 83.0, 83.5, 84.0

Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
MARINE PLATFORM (SUBAERIAL)	LIMESTONE INTRACLAST BRECCIA: GREY TO OLIVE, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS CLAY/SAND MATRIX, WELL INDURATED (HARD)	DISTURBED BRECCIATED TEXTURE	CLOSELY SPACED RANDOM DESSICATION FRACTURES	MODERATE INTERPARTICLE POROSITY	N/A	
MARINE	SUBMARINE LIMESTONE: GREY TO WHITE, OOLITHIC TEXTURE, WELL INDURATED, HEAVY BITUMEN STAIN	MOUNDED BIOLITHIC		HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		
NON-MARINE	SANDY CLAY: OLIVE, MASSIVE, POORLY CEMENTED (FRIABLE)	MASSIVE		HIGH INTERPARTICLE POROSITY		
MARINE (SUBAERIAL)	SUBMARINE LIMESTONE: GREY, OOLITHIC TEXTURE, HEAVY BITUMEN STAIN	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		
[illegible]	ARGILLACEOUS LIMESTONE					
[illegible]	SAND/CLAY					
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), BITUMEN STAIN, SOME SANDY HORIZONS	MARBLY TO FINELY INTERBEDDED W/ MICRITIC TEXTURE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 118	GROUND ELEVATION: 322.9 MASL
COREHOLE LOCATION: 8-20-94-9W4	DATE LOGGED: JUNE 9,1981

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
NON-MARINE	NON-CALCAREOUS SHALE: DK.BROWN TO GREY, FISSILE, MODERATELY WELL CEMENTED,	MASSIVE, TRACES OF LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME PLASTIC DEFORMATIONS	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
NON-MARINE	NON-CALCAREOUS SHALE: DK. BROWN TO GREY, FISSILE, MODERATELY WELL CEMENTED, SOME FINELY INTERBEDDED SILT/CLAY	SOME LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME PLASTIC DEFORMATIONS	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
NON-MARINE	SHALE: DK. BROWN, FISSILE, MODERATELY WELL CEMENTED, NON-FOSSILIFEROUS	SOME LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
NON-MARINE	SAND: BUFF, QUARTZITIC, WELL CEMENTED, MASSIVE					
NON-MARINE	BITUMINOUS SAND: BLACK DUE TO BITUMEN SATURATION, QUARTZITIC, WELL CEMENTED, MASSIVE					
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED, ABUNDANT FAUNA, BITUMEN STAIN, SOLUTION FEATURES FROM 66.1 - 67.8 M, SOME CONVOLUTED BEDDING	MARBLY TO FINELY INTERBEDDED W/ MICRITIC TEXTURE	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SUBVERTICAL SOLUTION PIPE INFILLED WITH OLIVE CLAY AND SOME SAND, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND VUGGY POROSITY	N/A	

DEPTH METRES: 60.7, 61.4, 62.1, 62.8, 63.5, 64.2, 64.9, 65.6, 66.3, 67.0, 67.7, 68.4, 69.1, 69.8, 70.5, 71.2, 71.9, 72.6, 73.3, 74.0, 74.7, 75.4, 76.1, 76.8, 77.5, 78.2, 78.9, 79.6, 80.3, 81.0, 81.7, 82.4, 83.1

Columns: DEPTH METRES; LITHOGRAPHIC SYMBOL; RECOVERY (MISSING CORE); SEDIMENTARY FACIES; LITHOLOGIC DESCRIPTION; PRIMARY STRUCTURE; SECONDARY STRUCTURE; POROSITY; PHOTOGRAPHIC PLATE; RQD

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 119	GROUND ELEVATION: 321.99 MASL
COREHOLE LOCATION: 11-20-94-9W4	DATE LOGGED: JULY 30,1991

Depth metres (scale): 54.5, 55.0, 55.5, 56.0, 56.5, 57.0, 57.5, 58.0, 58.5, 59.0, 59.5, 60.0, 60.5, 61.0, 61.5, 62.0, 62.5, 63.0, 63.5, 64.0, 64.5, 65.0, 65.5, 66.0, 66.5, 67.0, 67.5, 68.0, 68.5, 69.0, 69.5, 70.0

DEPTH METRES	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
55.0–57.0	MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE TO BUFF (WEATHERED), BIOLITHIC TEXTURE, WELL INDURATED (HARD), ABUNDANT FAUNA, HEAVY BITUMEN STAIN, SOME RECRYSTALLIZED CALCITE	ROUNDED BIOLITHIC TEXTURE	WIDELY SPACED RANDOM FRACTURES, BIOMOLDIC AND FRACTURE PERMEABILITY	HIGH BIOMOLDIC POROSITY		[illegible]
57.0–62.0	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME RECRYSTALLIZED CALCITE, MINOR WEATHERING ALONG FRACTURES	MARBLY TO FINELY INTERBEDDED (CM) LIMESTONE/SHALE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		[illegible]
62.0–62.5		DISTURBED ZONE; SUBANGULAR LIMESTONE FRAGMENTS IN CLAY MATRIX, HEAVY BITUMEN STAIN, BRECCIATED TEXTURE, POTENTIAL GOUGE MATERIAL	MASSIVE				
62.5–70.0	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (CM) LIMESTONE/SHALE, SHALY AT 67.5 M	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 120	GROUND ELEVATION 329.14 MASL
COREHOLE LOCATION 1-21-94-9W4	DATE LOGGED: AUGUST 4, 1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
81.5 – 82.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE					
82.0 – 84.5 (82.0, 82.5, 83.0, 83.5, 84.0, 84.5)			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), BITUMEN STAIN, SOME PYRITE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL COMPRESSION (?) FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	815	
84.5 – 90.0 (85.0, 85.5, 86.0, 86.5, 87.0, 87.5, 88.0, 88.5, 89.0, 89.5, 90.0)			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA, PYRITE	MAINLY TO FINELY INTERBEDDED MICRITIC TEXTURE, SOME NODULAR TEXTURES	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, OCC. SUBVERTICAL COMPRESSION (?) FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	[illegible], 815, 821, [illegible], [illegible]	
90.0 – 96.0 (90.5, 91.0, 91.5, 92.0, 92.5, 93.0, 93.5, 94.0, 94.5, 95.0, 95.5, 96.0)			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE AT 90 m; GREY, FISSILE, WELL CEMENTED (HARD), SOME PYRITE, ABUNDANT FAUNA	LAMINAE, SOME BEDDING	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
96.0 – 98.5 (96.5, 97.0, 97.5, 98.0, 98.5)			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	FINELY INTERBEDDED SHALE STRINGERS	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 121	GROUND ELEVATION: 323.70 MASL
COREHOLE LOCATION: 3-21-94-9W4	DATE LOGGED: AUGUST 5,1981

Depth (metres) scale: 74.8, 75.5, 76.3, 77.0, 77.8, 78.5, 79.3, 80.0, 80.8, 81.5, 82.3, 83.0, 83.8, 84.5, 85.3, 86.0, 86.8, 87.5, 88.3, 89.0, 89.8, 90.5, 91.3, 92.0, 92.8

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (BOXING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
74.8 – 86.0			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SOME WEATHERING DISCOLORATION IN UPPER 0.4 M, SUBHORIZONTAL ATTITUDE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	
86.0 – 88.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME PYRITE	MAINLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, TRACE OF BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		606 — 625	
88.3 – 91.3			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
91.3 – 92.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MAINLY TO FINELY INTERBEDDED (ON MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		775 — 778	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 123	GROUND ELEVATION 323.20 MASL
COREHOLE LOCATION 14-31-94-10W4	DATE LOGGED JULY 14,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
90.0 91.0 92.0			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE, SOME FINELY INTERBEDDED (C/W LIMESTONE STRINGERS	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY LOW FRACTURE POROSITY		N/A
93.0 94.0 95.0 96.0 97.0 98.0 99.0 100.0 101.0 102.0 103.0			MARINE PLATFORM (CARBONATE)	GRADES TO ARGILLACEOUS LIMESTONE; WHITE TO GREY MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), OCC. BIOSPARITIC ZONE (POTENTIAL HARDGROUND), SOME PYRITE	MAINLY TO FINELY INTERBEDDED (C/W MICRITIC TEXTURE, NODULAR TEXTURE AT 100-104 m	WIDELY SPACED SUBHORIZONTAL/SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY LOW FRACTURE POROSITY		97% 87% 37% 17% [illegible] 54%
104.0 105.0 106.0 107.0 108.0 109.0 110.0			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), SOME PYRITE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		51% 56% 57%

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 124	GROUND ELEVATION: 329.20 MASL
COREHOLE LOCATION: 1-22-94-9W4	DATE LOGGED: AUGUST 11,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
67.7 68.4 69.1 69.8 70.5 71.2 71.9 72.6 73.3 74.0 74.7 75.4 76.1 76.8 77.5 78.2 78.9 79.6			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED QUARTZ, SUBHORIZONTAL ATTITUDE, OCC. PYRITE NODULE, SOME WEATHERING ALONG FRACTURES	LAMINAE, SOME FINELY INTERBEDDED (CM) LIMESTONE STRINGERS	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL FRACTURE, SOME BOUDINAGE, MINOR WEATHERING, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY		N/A	
80.3 81.0 81.7			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN IN VERTICAL FRACTURES, MINOR SOLUTION FEATURES, ABUNDANT FAUNA	MARLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, MINOR WEATHERING, SOLUTION FEATURES (PIPE) AT SHALE/LIMESTONE CONTACT (UNCONFORMABLE CONTACT)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		[illegible] – [illegible]	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 125	GROUND ELEVATION: 327.57 MASL
COREHOLE LOCATION: AUGUST 6,1981	DATE LOGGED: 7-22-94-9W4

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY POSSIBLE CORED	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
[illegible] – [illegible]			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME WEATHERING DISCOLORATION	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
70.3 – [illegible]			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), SOME PYRITE NODULES, BITUMEN STAIN, FINELY INTERBEDDED AT 72.5 M	MARBLY TO FINELY INTERBEDDED (OR) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, OCC. INCLINED FRACTURE	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND BIOMOLDIC POROSITY		743 [illegible]	
[illegible] – [illegible]			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, BITUMEN STAIN, SOME BIOLITHIC ZONES, OCC. PYRITE NODULE, SOME WEATHERING DISCOLORATION ALONG FRACTURES	MARBLY TO FINELY INTERBEDDED MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		845 [illegible]	
[illegible] – [illegible]			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	

Depth scale (metres): [illegible], [illegible], 70.3, 71.0, 71.8, 72.6, 73.3, 74.0, 74.8, 75.6, 76.3, 77.0, 77.8, 78.6, 79.3, 80.0, 80.8, 81.6, 82.3, 83.0, 83.8, 84.6, [illegible]

DEVONIAN WATERWAYS [illegible]	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 126	GROUND ELEVATION: 324.8 MASL
COREHOLE LOCATION: 11-22-84-9W4	DATE LOGGED: JUNE 18, 1981

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURES	POROSITY	PHOTOGRAPHIC PLATE	RQD
MARINE PLATFORM (SHALE)	CALCAREOUS SHALE, BK. GREY TO OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA, SOME PYRITE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, OLIVE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE, ABUNDANT FAUNA, SOME RECRYSTALLIZED CALCITE	LAMINAE TO FINELY INTERBEDDED (CM) LIMESTONE/SHALE, SOME MARBLY TEXTURES	MODERATELY SPACED SUBHORIZONTAL/SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE (CARBONATE)	ARGILLACEOUS LIMESTONE, GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	FINELY INTERBEDDED (CM) LIMESTONE/SHALE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE	LIMESTONE/SHALE BRECCIA, GREY, SUBANGULAR LIMESTONE FRAGMENTS IN CALCAREOUS SHALE MATRIX	BRECCIATED TEXTURE	POTENTIAL COLLAPSE BRECCIA		N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, PYRITIC, SOME FAUNA (BRACHIOPODS)	MARBLY MICRITIC TEXTURE	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, GREY TO WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), SOME PYRITE NODULES	NODULAR TO FINELY INTERBEDDED LIMESTONE/SHALE, SOME LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA	FINELY INTERBEDDED LIMESTONE/SHALE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEPTH (METRES): 126.8, 127.2, 127.5, 127.8, 128.2, 128.5, 128.8, 129.3, 129.6, 130.0, 130.3, 130.7, 131.0, 131.4, 131.7, 132.1, 132.4, 132.8, 133.1, 133.5, 133.8, 134.2, 134.5, 134.8, 135.2, 135.5, 135.8, 136.2, 136.5, 137.0, 137.3, 137.7, 138.0, 138.4, 138.7, 139.1, 139.4, 139.8, 140.1, 140.5, 140.8, 141.2, 141.5, 141.8, 142.2, 142.5, 142.8

LITHOGRAPHIC SYMBOL / RECOVERY (BOREHOLE CORE)

DEVONIAN WATERWAYS FORMATION

COREHOLE NO. 127

COREHOLE LOCATION: 8-23-94-9W4

DESCRIPTIVE COREHOLE LOG

GROUND ELEVATION: 334.63 MASL

DATE LOGGED: AUGUST 11, 1981

DEPTH METRED	LITHOGRAPHIC SYMBOL	RECOVERY MISSING CORED	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
111.8 112.6 113.3 114.0 114.8 115.6 116.3 117.0 117.8 118.6			NON-MARINE	CLAY SHALE: DK. GREY, FISSILE, WELL CEMENTED (NON-CALCAREOUS), HIGHLY DESSICATED, NON-FOSSILIFEROUS, SOME SANDY HORIZONS, SOME BITUMEN STAIN	LAMINAE	MODERATELY SPACED DESSICATION (RANDOM) FRACTURES	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
119.3 120.0			NON-MARINE	NON-CALCAREOUS CLAY: GREY TO BUFF, WEATHERED (DISCOLORED), FISSILE	LAMINAE	DESSICATION FRACTURES			
120.8 121.6 122.3			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SOME FINELY INTERBEDDED LIMESTONE STRINGERS, SOME PYRITE	LAMINAE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
123.0 123.8 124.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), TRACE OF PYRITE	MARBLY MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	808	
125.3 126.0 126.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY TO WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), TRACE OF PYRITE	NODULAR TO FINELY INTERBEDDED (CM) TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
127.6 128.3 129.0 129.8 130.6 131.3 132.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY TO WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), BITUMEN STAIN, SOME SOLUTION FEATURES	MARBLY MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, KARST SOLUTION FEATURES (1 CM WIDE PIPE, INCLINED 15 DEGREES FROM VERTICAL, GREY, CALCAREOUS CLAY INFILLING), EXTENSIVE PYRITIZATION, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	808 813 875	
132.8 133.6 134.3 135.0 135.8 136.5			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE: GREY TO OLIVE, FISSILE, WELL CEMENTED (HARD), ABUNDANT FAUNA	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 120	GROUND ELEVATION: 320.00 MASL
COREHOLE LOCATION: 1-20-94-9W4	DATE LOGGED: JULY 29,1981

DEPTH METRED	LITHOGRAPHIC SYMBOL	RECOVERY (MISSING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
106.0 – 112.0 (106.0, 106.5, 107.0, 107.5, 108.0, 108.5, 109.0, 109.5, 110.0, 110.5, 111.0, 111.5, 112.0)			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA, PYRITE NODULES	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, WEATHERING ALONG FRACTURES, OCC. SUBVERTICAL COMPRESSION (?) FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		853 829 754
112.0 – 121.5 (112.5, 113.0, 113.5, 114.0, 114.5, 115.0, 115.5, 116.0, 116.5, 117.0, 117.5, 118.0, 118.5, 119.0, 119.5, 120.0, 120.5, 121.0, 121.5)			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE BELOW 112 M: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, PYRITE ALONG FRACTURES, SOME INTERBEDDED LIMESTONE STRINGERS, OCC. BIOLITHIC ZONE, SOME RECRYSTALLIZED CALCITE	LAMINAE, SOME FINELY INTERBEDDED (CM) LIMESTONE AT 110 M, MARBLY TEXTURE BELOW 110 M	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		873 738

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 129	GROUND ELEVATION: 320.98 MASL
COREHOLE LOCATION: 6-20-94-5W4	DATE LOGGED: JULY 13,1981

DEPTH (METRES)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
91.5 – 98.0	MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME INTERBEDDED LIMESTONE STRINGERS, PYRITE NODULES, ABUNDANT FAUNA (BRACHIOPODS)	LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL COMPRESSION (?) FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	535, 875	
98.0 – 108.5	MARINE PLATFORM (CARBONATE)	GRADES TO INTERBEDDED CARBONATE/SHALE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, PYRITE NODULES	MAINLY TO FINELY INTERBEDDED (OR MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	665, 515, 775, 586, 725, 438, 815	
108.5 – 109.5	NON-MARINE	CALCAREOUS SANDSTONE; GREY TO BUFF, FINE GRAINED, QUARTZITIC, WELL CEMENTED (VERY HARD), BITUMEN STAIN, SUBROUNDED PARTICLES (PHYSICALLY/CHEMICALLY MATURE)	WELL BEDDED (SUBHORIZONTAL DIP)	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND INTERPARTICLE PERMEABILITY	HIGH INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/R	
109.5 – 111.0	MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	641	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 130	GROUND ELEVATION: 315.40 MASL
COREHOLE LOCATION: 1-20-94-5W4	DATE LOGGED: SEPTEMBER 11,1981

Depth (metres), as marked: 68.1, 68.7, 69.3, 69.9, 70.5, 71.1, 71.7, 72.3, 72.9, 73.5, 74.1, 74.7, 75.3, 75.9, 76.5, 77.1, 77.7, 78.3, 78.9, 79.5, 80.1, 80.7, 81.3, 81.9, 82.5, 83.1, 83.7, 84.3, 84.9, 85.5

DEPTH (METRES)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
68.1–77.7	MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS	LAMINAE, FINELY INTERBEDDED (C?) LIMESTONE STRINGERS	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/R	
77.7–80.1	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, OCC. PYRITE NODULE, SOME FAUNA (BRACHIOPODS)	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	813, 1005	
80.1–82.5	MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	NODULAR TO LAMINAR TEXTURE	MODERATELY SPACED SUBVERTICAL COMPRESSION (?) FRACTURES, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	888	
82.5–85.5	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/R	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 131	GROUND ELEVATION: 322.30 MASL
COREHOLE LOCATION: 5-29-94-5W4	DATE LOGGED: SEPTEMBER 3, 1981

Depth (metres): 69.0, 70.0, 71.0, 72.0, 73.0, 74.0, 75.0, 76.0, 77.0, 78.0, 79.0, 80.0, 81.0, 82.0, 83.0, 84.0, 85.0, 86.0, 87.0, 88.0, 89.0

Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
	CLAY/SAND: WHITE, LIMEY TEXTURE, QUARTZITIC, WELL CEMENTED SAND, BITUMEN STAIN, TRACE OF PYRITE	MASSIVE	RANDOM DESICCATION FRACTURES			
MARINE PLATFORM (CARBONATE)	GRADES TO ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN, SOME INTERBEDDED BIOSPARITIC ZONES (POTENTIAL HARDGROUND SURFACES)	FINELY INTERBEDDED (CM TO LAMINAR, SOME MARBLY MICRITIC TEXTURES, OCC. HARDGROUND SURFACE	SOME BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED SUBVERTICAL/INCLINED FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (SHALE/ CARBONATE)	FINELY INTERBEDDED LIMESTONE/SHALE GRADES TO CALCAREOUS SHALE BELOW 78 m WHITE TO GREY, MICROCRYSTALLINE LIMESTONE, GREY FISSILE CALCAREOUS SHALE INTERBEDS, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN, SOME PYRITE	FINELY INTERBEDDED TO LAMINAR, SOME BIOSPARITIC HARDGROUNDS	EXTENSIVE BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 132	GROUND ELEVATION: 324.25 MASL
COREHOLE LOCATION: 11-29-94-5W4	DATE LOGGED: AUGUST 7,1981

Depth metred: 73.8, 74.7, 75.6, 76.4, 77.2, 78.1, 78.9, 79.8, 80.6, 81.5, 82.3, 83.2, 84.0, 84.9, 85.7, 86.6, 87.4, 88.3, 89.1, 90.0, 90.8, 91.7, 92.5, 93.4, 94.2, 95.1, 95.9, 96.8, 97.6, 98.5, 99.3, 100.2, 101.0, 101.9, 102.7, 103.6

Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
NON-MARINE	SAND/SILT/CLAY: GREY TO BROWN, MODERATELY INDURATED (HARD), NON-CALCAREOUS, SOME PYRITE, SOME CARBONACEOUS STRINGERS, MINOR WEATHERING (OXIDATION STAIN), SOME BRITTLE DISPLACEMENTS, NON-FOSSILIFEROUS	LAMINAE, SOME CROSSBEDDING, CLAYS ARE FISSILE	DESSICATION FRACTURES, BRITTLE DISPLACEMENT FEATURES (POTENTIAL SLUMP)	MODERATE INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
NON-MARINE	SAND: BUFF, MEDIUM GRAINED, POORLY CEMENTED (FRIABLE), CLEAN	TRACE OF BEDDING		HIGH INTERPARTICLE POROSITY	N/A	
MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SOME PYRITE, OCC. FAUNA, SOME FINELY INTERBEDDED LIMESTONE AT 90 M, GRADES TO MASSIVE SHALE BELOW 94 M	LAMINAE, SOME FINELY INTERBEDDED (CM) LIMESTONE STRINGERS	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), MINOR WEATHERING (DISCOLORATION)	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		84% 68%

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 133	GROUND ELEVATION: 321.23 MASL
COREHOLE LOCATION: 15-29-94-9W4	DATE LOGGED: JULY 28,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY POOR CORE	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
77.0 77.5 78.0 78.5 79.0 79.5			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	MODERATELY SPACED SUBHORIZONTAL/SUBVERTICAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
80.0 80.5 81.0 81.5 82.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), HIGH ARGILLACEOUS CONTENT, HIGHLY FOSSILIFEROUS	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	835 836	
82.5 83.0			MARINE (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	889	
83.5 84.0 84.5			MARINE (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS)	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
85.0 85.5 86.0			MARINE (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SOME PYRITE, MINOR WEATHERING (DISCOLORATION)	LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
86.5 87.0 87.5 88.0 88.5 89.0 89.5 90.0 90.5 91.0 91.5			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MARBLY MICRITIC TEXTURE, SOME FINELY INTERBEDDED (CM) ZONES	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, WIDELY SPACED SUBVERTICAL COMPRESSION (?) FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	743 763 715	
92.0 92.5 93.0			MARINE (SHALE)	GRADES TO CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SOME PYRITE NODULES	LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	511	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 134	GROUND ELEVATION 322.84 MASL
COREHOLE LOCATION 1-30-94-9W4	DATE LOGGED: SEPTEMBER 11,1981

Depth metres: 60.5 – 76.0 (0.5 m intervals)

Lithographic Symbol	Recovery Coring Cored	Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
		MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, MODERATELY INDURATED (HARD), WELL WEATHERED IN UPPER 0.5 m OXIDATION STAIN, BITUMEN STAIN, SOME SOLUTION FEATURES	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME RANDOM FRACTURES, FRACTURE PERMEABILITY, SOLUTION FEATURES	MODERATE SOLUTION/FRACTURE POROSITY, VERY LOW INTERPARTICLE POROSITY		N/A
		MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FRIABLE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, POTENTIAL HARDGROUND SURFACES	BEDDING LAMINAE, SOME NODULAR TEXTURES	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
		MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE GRADES TO CALCAREOUS SHALE AT 68 m; GREY, MICROCRYSTALLINE, POORLY INDURATED, SUBHORIZONTAL ATTITUDE, FRIABLE AT HIGHLY FRACTURED HORIZONS	MARBLY TO FINELY INTERBEDDED (?) MICRITIC TEXTURE, SOME LAMINAE IN SHALES	EXTENSIVE BOUDINAGE, CLOSELY SPACED SUBVERTICAL AND SUBHORIZONTAL FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY		N/A
		MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE GRADES TO CALCAREOUS SHALE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MARBLY TO FINELY INTERBEDDED (?) MICRITIC TEXTURES	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 135	GROUND ELEVATION: 328.31 MASL
COREHOLE LOCATION: 3-30-94-SW4	DATE LOGGED: AUGUST 18,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (BLENDING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
58.3			NON-MARINE	CLAY						
59.0 59.8			NON-MARINE	CLAY						
60.5 61.3 62.0 62.8 63.5 64.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO OLIVE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, EXTENSIVE SOLUTION FEATURES (SLUMPED BEDDING, PIPES), SOME FAUNA (BRACHIOPODS)	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, EXTENSIVE SOLUTION PIPES INFILLED WITH LIMESTONE CLAST/CLAY MATRIX, OCC. RANDOM FRACTURE	VERY LOW INTERPARTICLE POROSITY, MODERATE TO HIGH FRACTURE/SOLUTION VOID POROSITY		N/A	
65.0			NON-MARINE	BITUMINOUS SANDS						
65.8 66.5			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME SOLUTION FEATURES	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOLUTION FEATURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
67.3 68.0 68.8 69.5 70.3 71.0			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, BIOLITHIC TEXTURE, WELL INDURATED (HARD), HEAVY BITUMEN STAIN, SOME RECRYSTALLIZED CALCITE, SOLUTION PIPE INFILLED WITH LT. GREEN PLASTIC CLAY, UPPER 1 M - COQUINA PACKSTONE	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOLUTION PIPE, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		606 415 206	
71.8 72.5 73.3 74.0 74.8 75.5 76.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 136	GROUND ELEVATION: 322.3 MASL
COREHOLE LOCATION: 1-31-94-9W4	DATE LOGGED: JUNE 16,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
76.2 76.8 77.4 78.0 78.6 79.2 79.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, EXTENSIVE SOLUTION FEATURES (PIPE INFILLED WITH BEDDED, LT. GREEN SAND/CLAY, SOME LIMESTONE FRAGMENTS), BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	EXTENSIVE SOLUTION FEATURES (PIPE DIMENSIONS 2-3 CM X 50-70 CM), WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	MODERATE FRACTURE AND SOLUTION VOID POROSITY	N/A	
80.4 81.0 81.6 82.2 82.8 83.4 84.0 84.6 85.2 85.8 86.4 87.0 87.6 88.2 88.8 89.4 90.0 90.6 91.2 91.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA (BRACHIOPODS), SOME RECRYSTALLIZED CALCITE, INCREASING ARGILLACEOUS CONTENT BELOW 85 M	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES,POTENTIAL HARDGROUND SURFACE AT 91 M (BIOSPARITIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND BIOMOLDIC POROSITY	N/A	

Descriptive Corehole Log

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 137	GROUND ELEVATION: 317.49 MASL
COREHOLE LOCATION: 11-30-94-5W4	DATE LOGGED: AUGUST 12, 1981

Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
MARINE PLATFORM CARBONATE	ARGILLACEOUS LIMESTONE, GREY TO RUST WEATHERED, MICROCRYSTALLINE, WELL INDURATED [illegible] HARD, SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME PYRITE	NODULAR MICRITIC TEXTURE	EXTENSIVE SOLUTION (PIPES), MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOLUTION VOID/FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE SOLUTION VOID AND FRACTURE POROSITY	N/A	
MARINE PLATFORM CARBONATE	ARGILLACEOUS LIMESTONE, GREY, MICROCRYSTALLINE, WELL INDURATED [illegible] HARD, SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, PYRITIZED PIPE WALLS, [illegible] GRAINED QUARTZ SAND/CLAY INFILLING, SHALY AT [illegible]	NODULAR TO FINELY INTERBEDDED [illegible] MICRITIC TEXTURE	EXTENSIVE SOLUTION (PIPES), WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOLUTION VOID/FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 130	GROUND ELEVATION: 314.41 MASL
COREHOLE LOCATION: 13-31-94-10W4	DATE LOGGED: AUGUST 12, 1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY PERCENTAGE (RQD)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
60.8 61.6 62.3 63.0			MARINE [illegible]	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN IN VERTICAL FRACTURES	FINELY INTERBEDDED (CM) LIMESTONE/SHALE	EXTENSIVE BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	
63.8 64.6 65.3 66.0				GRADES TO CALCAREOUS SHALE BELOW 63					
66.8 67.6 68.3 69.0 69.8 70.6				GRADES TO FINELY INTERBEDDED CARBONATE/SHALE BELOW 66					
71.3 72.0 72.8 73.6 74.3 75.0			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SOME PYRITE NODULES	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 130	GROUND ELEVATION: 320.9 MASL
COREHOLE LOCATION: 3-32-94-9W4	DATE LOGGED: JUNE 18, 1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
70.7									
71.4, 72.1, 72.8, 73.5, 74.2, 74.9, 75.6, 76.3, 77.0, 77.7, 78.4, 79.1			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY TO OLIVE, FISSILE, WELL CEMENTED, SUBHORIZONTAL ATTITUDE	LAMINATIONS	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
79.8, 80.5, 81.2			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED, SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA BRACHIOPODS, SOME BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
81.9, 82.6, 83.3, 84.0			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY TO OLIVE, FISSILE, WELL CEMENTED, SUBHORIZONTAL ATTITUDE, PYRITE NODULES AT 84.2 M	LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
84.7, 85.4, 86.1, 86.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED, SUBHORIZONTAL ATTITUDE, NUMEROUS BIOLITHIC ZONES, POTENTIAL INTRAFORMATIONAL UNCONFORMITY AT 84.2	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 14B	GROUND ELEVATION 320.77 MASL
COREHOLE LOCATION 5-32-94-9W4	DATE LOGGED JUNE 29,1981

Depth markers (metres): 88.7, 89.4, 90.1, 90.8, 91.5, 92.2, 92.9, 93.6, 94.3, 95.0, 95.7, 96.4, 97.1, 97.8, 98.5, 99.2, 99.9, 100.6, 101.3, 102.0, 102.7, 103.4

Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE, OCC. LIMESTONE INTERBED	LAMINAE, OCC. INTERBEDDED LIMESTONE STRINGER	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, WELL INDURATED (VERY HARD),SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS)	MAINLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, WELL CEMENTED (HARD), SOME LIMESTONE NODULES	LAMINAR TO NODULAR TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME FRACTURES ABOUT NODULES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, OCC. BIOLITHIC ZONE, SOME HIGHLY MICRITIC HORIZONS, ABUNDANT FAUNA (BRACHIOPODS)	MASSIVE TO NODULAR TEXTURE, SOME BIOLITHIC BEDS	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 141	GROUND ELEVATION: 319.85 MASL
COREHOLE LOCATION: 8-32-94-8W4	DATE LOGGED: JUNE 29,1981

DEPTH METRES: 81.7, 82.4, 83.1, 83.8, 84.5, 85.2, 85.9, 86.6, 87.3, 88.0, 88.7, 89.4, 90.1, 90.8, 91.5, 92.2, 92.9, 93.6, 94.3, 95.0, 95.7, 96.4

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, MINOR SOLUTION FEATURES, SOME FAUNA, SOME SANDY ZONES	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE, GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), SOME PYRITE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	GRADES TO FINELY INTERBEDDED LIMESTONE/SHALE, GREY, LAMINAR TO FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA	LAMINAR TO FINELY INTERBEDDED LIMESTONE/SHALE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	[illegible]
COREHOLE NO: 142	GROUND ELEVATION: [illegible]70.18 MASL
COREHOLE LOCATION: 11-32-94-9W4	DATE LOGGED: AUGUST 10,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (FOOTAGE CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
84.5 – 88.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, MINOR WEATHERING DISCOLORATION IN UPPER 0.3 M, BITUMEN STAIN, SOME PYRITE IN FRACTURES, OCC. BIOSPARITIC ZONE	MARBLY TO NODULAR MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	298 853 883	
88.0 – 97.0			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE, TRACE OF FAUNA (BRACHIOPODS), OCC. BIOLITHIC (COQUINA) ZONE, FINELY INTERBEDDED LIMESTONE/SHALE AT 94	LAMINAE, SOME INTERBEDDED COQUINA	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	843	
97.0 – 100.0			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, OCC. PYRITE, TRACE OF FAUNA	LAMINAE, SOME FINELY INTERBEDDED (CM) LIMESTONE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 143	GROUND ELEVATION: 338.97 MASL
COREHOLE LOCATION: 7-1-94-10W4	DATE LOGGED: AUGUST 8,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (FORMING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
80.7 81.4 82.1 82.8 83.5 84.2 84.9 85.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME BITUMEN STAIN, EXTENSIVE KARST SOLUTION FEATURES (8 CM WIDE PIPE INFILLED WITH OLIVE, SANDY CLAY, SOME COLLAPSE BRECCIA)	MARBLY MICRITIC TEXTURE	SOME BOUDINAGE, EXTENSIVE SOLUTION FEATURES, LOW DENSITY SUBHORIZONTAL TENSION FRACTURES, SOLUTION VOID AND FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE SOLUTION VOID AND FRACTURE POROSITY		798 1003 841 838
86.3 87.0 87.7 88.4 89.1 89.8 90.5			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME RUBBLY TEXTURES	NODULAR TO INTERBEDDED LIMESTONE/SHALE TEXTURE	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
91.2 91.9 92.6 93.3			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, BIOLITHIC TEXTURE, HEAVY BITUMEN STAIN, KARST SOLUTION PIPE INFILLED WITH FINE/MEDIUM GRAINED BITUMINOUS SANDS	MOUNDED, BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, KARST SOLUTION FEATURES, FRACTURE AND SOLUTION VOID PERMEABILITY	HIGH BIOMOLDIC AND SOLUTION VOID POROSITY, LOW FRACTURE POROSITY		838 715
94.0 94.7 95.4 96.1 96.8 97.5 98.2 98.9 99.6 100.3 101.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), SOME BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		538 375 725 151 875

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 144	GROUND ELEVATION: 328.28 MASL
COREHOLE LOCATION: 9-1-94-10W4	DATE LOGGED: SEPTEMBER 10,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
62.7, 63.4, 64.1, 64.8, 65.5, 66.2, 66.9, 67.6, 68.3, 69.0, 69.7, 70.4, 71.1			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, MODERATELY INDURATED (HARD), HIGH MICRITE CONTENT, SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, MINOR SOLUTION FEATURES	MAINLY MICRITIC TEXTURE	MINOR SOLUTION PIPES, MODERATELY SPACED SUBHORIZONTAL/RANDOM FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		673, 463, 615, 573, 883
71.8, 72.5, 73.2, 73.9, 74.6, 75.3			MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA; GREY, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS CLAY MATRIX, MODERATELY INDURATED, MINOR SOLUTION FEATURES	SUBTLE BEDDING, BRECCIATED TEXTURE, SOME LAMINAE	WIDELY SPACED SUBHORIZONTAL FRACTURES, SOME RANDOM FRACTURES, SOME MINOR SOLUTION PIPES, FRACTURE AND SOLUTION PIPE PERMEABILITY	LOW INTERPARTICLE AND FRACTURE POROSITY		771
76.0, 76.7, 77.4, 78.1			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, BIOLITHIC TEXTURE, WELL INDURATED (HARD), LIGHT BITUMEN STAIN, SUBTLE BEDDING PLANES, UNDISTURBED	ROUNDED BIOLITHIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		715, 883
78.8, 79.5, 80.2, 80.9			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, BITUMEN STAIN	MAINLY TO FINELY INTERBEDDED (C/M) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 145	GROUND ELEVATION: 328.9 MASL
COREHOLE LOCATION: 11-1-94-10W4	DATE LOGGED: JUNE 11,1981

DEPTH (METRES)
67.2
67.9
68.6
69.3
70.0
70.7
71.4
72.1
72.8
73.5
74.2
74.9
75.6
76.3
77.0
77.7
78.4
79.1
79.8
80.5
81.2
81.9
82.6
83.3
84.0
84.7
85.4
86.1

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME SIDERITE GRAINS (SPHAEROSIDERITES)	MARBLY TO NODULAR MICRITIC TEXTURES	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SUBVERTICAL FRACTURES, SOME KARST SOLUTION FEATURES (PIPES), FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW TO MODERATE FRACTURE/SOLUTION VOID POROSITY	N/A	
MARINE	ARGILLACEOUS LIMESTONE					
MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA; WHITE, ANGULAR LIMESTONE INCLUSIONS IN GREY CALCAREOUS CLAY MATRIX, SOME BITUMEN STAIN, MODERATELY WELL CEMENTED	MOUNDED, BRECCIATED TEXTURE, DISTURBED (SLUMPED) BEDDING	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, WELL INDURATED (VERY HARD), SOME BITUMEN STAIN, ABUNDANT FAUNA	MOUNDED, BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL AND SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY TO OLIVE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS)	FINELY INTERBEDDED (CM) LIMESTONE/SHALE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 146	GROUND ELEVATION: 313.2 MASL
COREHOLE LOCATION: 12-2-94-10W4	DATE LOGGED: JUNE 10,1981

Depth (metres): 42.5, 43.0, 43.5, 44.0, 44.5, 45.0, 45.5, 46.0, 46.5, 47.0, 47.5, 48.0, 48.5, 49.0, 49.5, 50.0, 50.5, 51.0, 51.5, 52.0, 52.5, 53.0, 53.5, 54.0, 54.5, 55.0, 55.5, 56.0, 56.5, 57.0, 57.5, 58.0, 58.5, 59.0, 59.5

Depth (Metres)	Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, OCC. PYRITE NODULE, SOME BITUMEN STAIN, MINOR SOLUTION PIPE	NODULAR TO FINELY INTERBEDDED (C/N) TEXTURE, SOME MARBLY MICRITIC TEXTURE	SOME SOLUTION FEATURES (PIPE), MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY	N/A	
	MARINE PLATFORM (CARBONATE)	FRAGMENTAL LIMESTONE; GREY, FRAGMENTAL, FRIABLE, MODERATELY WEATHERED, SOME BITUMEN STAIN	MARBLY TO RUBBLY TEXTURE	CLOSELY SPACED RANDOM COMPRESSION (?) FRACTURES, FRACTURE PERMEABILITY	LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	NODULAR TO FINELY INTERBEDDED (C/N) LIMESTONE/SHALE TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
	MARINE PLATFORM	ARGILLACEOUS LIMESTONE; WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), POTENTIAL INTRAFORMATIONAL UNCONFORMITY AT 53.8 M (CLAY INFILLING, ANGULAR DISCONTINUITY)	BEDDING	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA (BRACHIOPODS)	MARBLY TO FINELY INTERBEDDED (C/N) MICRITIC TEXTURE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
	MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, BIOLITHIC TEXTURE, WELL INDURATED (HARD), SOME RECRYSTALLIZED CALCITE, SOME MICRITE	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 147	GROUND ELEVATION: 311.49 MASL
COREHOLE LOCATION: 4-11-94-10W4	DATE LOGGED: JULY 27,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (DIAMOND CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
42.7 – 55.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, OCC. ARGILLACEOUS STRINGER, SOME WEATHERING (DISCOLORATION), OCC. BIOLITHIC ZONE, SOME FAUNA (BRACHIOPODS)	MARBLY MICRITIC TEXTURE, SOME INTERBEDDED SHALE, OCC. BIOLITHIC HARDGROUND	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		85% 85% 79% 82% 53% 78% 59% 58%
56.0 – 59.5			MARINE PLATFORM (CARBONATE)	GRADES TO HIGHLY ARGILLACEOUS LIMESTONE BELOW 55.5 m GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME BITUMEN STAIN	FISSILE TO MARBLY MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		54% 53% 56%

Depth scale (metres): 42.7, 43.4, 44.1, 44.8, 45.5, 46.2, 46.9, 47.6, 48.3, 49.0, 49.7, 50.4, 51.1, 51.8, 52.5, 53.2, 53.9, 54.6, 55.3, 56.0, 56.7, 57.4, 58.1, 58.8, 59.5

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 140	GROUND ELEVATION: 312.67 MASL
COREHOLE LOCATION: 11-11-94-10W4	DATE LOGGED: JULY 22,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERIODIC CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
29.7									
30.4			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE NODULES, SOME WEATHERING (DISCOLORATION) ALONG FRACTURES, SOME RECRYSTALLIZED CALCITE	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE, HIGHLY ARGILLACEOUS BELOW 37.0 (FISSILE)	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL/SUBVERTICAL FRACTURES, MINOR WEATHERING, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A
31.1									
31.8									
32.5									
33.2									
33.9									
34.6									
35.3									
36.0									
36.7									
37.4									
38.1									
38.8									
39.5									
40.2									
40.9									
41.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HIGH MICRITE CONTENT	MARBLY MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
42.3									
43.0									
43.7									
44.4									
45.1									
45.8									

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 149	GROUND ELEVATION: 321.53 MASL
COREHOLE LOCATION: 2-12-94-10W4	DATE LOGGED: AUGUST 17,1981

Depth (metres): 60.8, 61.5, 62.3, 63.0, 63.8, 64.5, 65.3, 66.0, 66.8, 67.5, [illegible], 69.0, 69.8, 70.5, 71.3, 72.0, 72.8, 73.5, 74.3, 75.0, 75.8, 76.5, 77.3, 78.0, 78.8, 79.5

Depth Metred	Lithographic Symbol	Recovery (Missing Core)	Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity		Photographic Plate	RQD
60.8 – 63.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED SUBVERTICAL FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		583, 625	
63.8 – 66.0			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE BELOW 64 m GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE, SOME NODULAR LIMESTONE TEXTURES	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, TRACE OF BOUDINAGE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
66.0 – 74.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE, LAMINAR BELOW 70 m	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		603, 573, 583, 715, 798, 825	
74.3 – 79.5			MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA; WHITE TO GREY, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS CLAY MATRIX, BITUMEN STAIN, SOME FAUNA	TRACE OF BEDDING	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	
79.5			MARINE	BIOHERMAL LIMESTONE; WHITE, WELL INDURATED	BIOLITHIC	SUBHORIZONTAL TENSION FRACTURES	HIGH BIOMOLDIC POROSITY		835	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 150	GROUND ELEVATION: 320.33 MASL
COREHOLE LOCATION: 11-12-94-10W4	DATE LOGGED: JULY 22,1981

DEPTH (METRES)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
64.5, 66.0, 67.5, 69.0	MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: OLIVE, FISSILE, WELL CEMENTED (HARD), SOME SANDY HORIZONS, SOME FINELY INTERBEDDED (CM) LIMESTONE STRINGERS, MINOR WEATHERING DISCOLORATION	LAMINAE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
70.5, 72.0, 73.5, 75.0, 76.5, 78.0, 79.5	MARINE PLATFORM (CARBONATE)	GRADES TO ARGILLACEOUS LIMESTONE: WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, MINOR WEATHERING DISCOLORATION, MASSIVE BELOW 78.0M	MARBLY MICRITIC TEXTURE, SOME LAMINAE IN SHALY SECTIONS	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
81.0, 82.5	MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: WHITE, BIOLITHIC TEXTURE, WELL INDURATED (HARD), SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
84.0, 85.5, 87.0, 88.5, 90.0, 91.5	NON-MARINE	NON-CALCAREOUS CLAY/SAND: DK. GREY, FISSILE, MODERATELY WELL CEMENTED, SOME BITUMEN STAIN, SOME SAND STRINGERS BELOW 88.7M	SOME LAMINAE, SOME BEDDING IN SANDY ZONES	DESSICATION FRACTURES, CLOSELY SPACED RANDOM FRACTURES, FRACTURE AND INTERPARTICLE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
93.0, 94.5	NON-MARINE	NON-CALCAREOUS SHALE: OLIVE TO DK. GREY, FISSILE, MODERATELY CEMENTED (FRIABLE), HIGHLY DESSICATED	LAMINAE	MODERATELY SPACED RANDOM DESSICATION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
96.0, 97.5, 99.0, 100.5, 102.0, 103.5, 105.0, 106.5, 108.0	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), SOME PYRITE NODULES, HARDGROUND AT 105.7	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 151	GROUND ELEVATION 322.21 MASL
COREHOLE LOCATION 10-12-94-10W4	DATE LOGGED AUGUST 12,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY [illegible] CARD	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
73.0 73.5 74.0 74.5 75.0 75.5 76.0 76.5 77.0 77.5 78.0 78.5 79.0			MARINE PLATFORM CARBONATE	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED VERY HARD, SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN IN SUBVERTICAL FRACTURES, MARBLY TEXTURE AT 78	MARBLY TO FINELY INTERBEDDED ECD MICRITIC TEXTURE	CLOSELY SPACED SUBHORIZONTAL FRACTURES, SOME BOUDINAGE, OCC. SUBVERTICAL FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	
79.5 80.0 80.5 81.0 81.5 82.0 82.5 83.0 83.5			MARINE PLATFORM CARBONATE	GRADES TO SHALY LIMESTONE, GREY, FISSILE TO FINELY INTERBEDDED, WELL CEMENTED, SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, RUBBLY BRECCIA AT 83 M	LAMINAE, FINELY INTERBEDDED LIMESTONE/SHALE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY, POTENTIAL COLLAPSE FEATURE AT 83 M BRECCIA	LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION

COREHOLE NO. 152

COREHOLE LOCATION: 5-13-94 9W4

DESCRIPTIVE COREHOLE LOG

GROUND ELEVATION: 328.53 MASL

DATE LOGGED: JULY 28, 1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (RECEIVING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
55.5									
56.0 – 59.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, RANDOM COMPRESSION FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
59.5 – 64.0			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY TO OLIVE, FISSILE, WELL CEMENTED (HARD), SLIGHTLY WEATHERED (DISCOLOURED) at 62.2M, SOME PYRITE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
64.5 – 65.0			MARINE PLATFORM (SHALE)	WEATHERED ZONE DISCOLOURED					
65.5 – 70.5			MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA: WHITE, SUBANGULAR LIMESTONE CLASTS IN GREY CALCAREOUS SHALE MATRIX, GRADES TO ARGILLACEOUS LIMESTONE: WHITE, MICROCRYSTALLINE, WELL INDURATED, SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA, BITUMEN STAIN	DISTURBED BRECCIATED APPEARANCE, MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WEATHERED HORIZON AT 66.2M, INCLINED SOLUTION PIPE (2 CM WIDE) BELOW BRECCIA, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SUBVERTICAL FRACTURES (BITUMEN STAINED), FRACTURE/SOLUTION PIPE PERMEABILITY (ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY	825 [illegible] 836 786	
71.0			MARINE PLATFORM	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA	LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

Depth scale (metres): 55.5, 56.0, 56.5, 57.0, 57.5, 58.0, 58.5, 59.0, 59.5, 60.0, 60.5, 61.0, 61.5, 62.0, 62.5, 63.0, 63.5, 64.0, 64.5, 65.0, 65.5, 66.0, 66.5, 67.0, 67.5, 68.0, 68.5, 69.0, 69.5, 70.0, 70.5, 71.0

DEVONIAN WATERWAYS FORMATION

COREHOLE NO: 153

COREHOLE LOCATION: 7-13-94 W4

DESCRIPTIVE COREHOLE LOG

GROUND ELEVATION: 322.04 MASL

DATE LOGGED: JULY 16 1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (MISSING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
56.8 – 59.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY TO BUFF, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME SOLUTION FEATURES (PIPE), UPPER 0.4 M WEATHERED (DISCOLOURED), POTENTIAL INTRAFORMATIONAL UNCONFORMITY AT 57.9 M	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SOLUTION FEATURES, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	75% 74%	
59.8			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: WHITE, WELL INDURATED, SOME RECRYSTALLIZED CALCITE, HEAVY BITUMEN STAIN	BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
60.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE, MICROCRYSTALLINE, WELL INDURATED, SUBHORIZONTAL ATTITUDE	MARBLY TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	46%	
61.3			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: WHITE, WELL INDURATED, HEAVY BITUMEN STAIN	BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
62.0 – 63.6			MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA: WHITE, SUBANGULAR LIMESTONE INCLUSIONS IN OLIVE CALCAREOUS CLAY MATRIX, DISTURBED SLUMPED BEDDING, SOME WEATHERING OXIDATION STAINS, BITUMEN STAIN	DISTURBED, BRECCIATED TEXTURE	WIDELY SPACED RANDOM FRACTURES, SLUMPED BEDDING PLANES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	75%	
64.3 – 70.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), BITUMEN STAIN, SOME PYRITE, OCC. HARD BIOLITHIC ZONE (POTENTIAL HARDGROUND)	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	77% 38%	
70.3 – 79.3			MARINE PLATFORM (CARBONATE)	SHALY BELOW 70.8 M, MARBLY MICRITIC TEXTURE AT 71.4 M, SHALY BELOW 73.8 M, MARBLY TO NODULAR MICRITIC TEXTURES BELOW 75	SHALES ARE LAMINAR	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	32% 39%	

Depth markers (m): 56.8, 57.6, 58.3, 59.0, 59.8, 60.6, 61.3, 62.0, 62.8, 63.6, 64.3, 65.0, 65.8, 66.6, 67.3, 68.0, 68.8, 69.6, 70.3, 71.0, 71.8, 72.6, 73.3, 74.0, 74.8, 75.6, 76.3, 77.0, 77.8, 78.6, 79.3

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 154	GROUND ELEVATION: 323.42 MASL
COREHOLE LOCATION: 9-13-94-10W4	DATE LOGGED: SEPTEMBER 9,1981

Depth metred: 60.7, 61.4, 62.1, 62.8, 63.5, 64.2, 64.9, 65.6, 66.3, 67.0, 67.7, 68.4, 69.1, 69.8, 70.5, 71.2, 71.9, 72.6, 73.3, 74.0, 74.7, 75.4, 76.1, 76.8, 77.5, 78.2, 78.9, 79.6, 80.3, 81.0, 81.7

Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN, SOLUTION PIPE INFILLED WITH LT. GREEN CLAY	MARBLY MICRITIC TEXTURE	WIDELY SPACED RANDOM FRACTURES, SUBVERTICAL SOLUTION PIPE, FRACTURE AND SOLUTION PIPE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY		100%
MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA; WHITE, SUBANGULAR LIMESTONE INCLUSIONS IN GREY CALCAREOUS CLAY MATRIX, MASSIVE, MODERATELY WELL CEMENTED	DISTURBED BRECCIATED TEXTURE		LOW INTERPARTICLE POROSITY		72%
MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, BIOLITHIC TEXTURE, WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN, MINOR SOLUTION FEATURES, ABUNDANT FAUNA	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, BIOMOLDIC AND FRACTURE PERMEABILITY, SOME SOLUTION PIPES	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		N/A
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		80%
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, GRADES TO CALCAREOUS SHALE BELOW 80 M	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		54% 40%
MARINE	ARGILLACEOUS LIMESTONE	MARBLY TEXTURE				N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 155	GROUND ELEVATION: 221.0 MASL
COREHOLE LOCATION: 11-13-94-10W4	DATE LOGGED: JUNE 8, 1981

DEPTH METRED	LITHOGRAPHIC SYMBOL	RECOVERY (ROCKING CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
56.5 57.0 57.5			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: BUFF (WEATHERED) TO GREY, MARBLY TO NODULAR TEXTURES, WELL INDURATED, SUBHORIZONTAL ATTITUDE, SOME BITUMEN STAIN, SOME FAUNA	MARBLY TO NODULAR MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
58.0 58.5 59.0 59.5 60.0 60.5 61.0 61.5 62.0 62.5 63.0 63.5 64.0 64.5 65.0 65.5 66.0 66.5 67.0 67.5 68.0 68.5 69.0 69.5			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO OLIVE/GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODA), BITUMEN STAIN IN SUBVERTICAL FRACTURES, SLIGHT WEATHERING DISCOLORATIONS OF UPPER HORIZON, SOME PLASTIC CLAY	MARBLY TO FINELY INTERBEDDED (?) MICRITIC TEXTURE	KARST SOLUTION FEATURES BELOW 61 M, EXTENSIVE BOUDINAGE, WIDELY SPACED SUBHORIZONTAL/SUBVERTICAL TENSION FRACTURES, FRACTURE AND SOLUTION PIPE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 158	GROUND ELEVATION: 322.49 MASL
COREHOLE LOCATION: 15-13-94-9W4	DATE LOGGED: JULY 14, 1981

Depth (metres): 66.5, 67.0, 67.5, 68.0, 68.5, 69.0, 69.5, 70.0, 70.5, 71.0, 71.5, 72.0, 72.5, 73.0, 73.5, 74.0, 74.5, 75.0, 75.5, 76.0, 76.5, 77.0, 77.5, 78.0, 78.5, 79.0, 79.5, 80.0, 80.5, 81.0, 81.5, 82.0, 82.5

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
MARINE	CALCAREOUS CLAY; OLIVE, SUBTLE FISSILITY, WELL CEMENTED	LAMINAE	WIDELY SPACED DESSICATION FRACTURES			28%
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE NODULES, ABUNDANT FAUNA, SOME SOLUTION FEATURES (PIPE), WEATHERED (DISCOLORED) AT 67.2	MARBLY MICRITIC TEXTURE, FINELY INTERBEDDED (C?) AT 71 M	SOME BOUDINAGE BELOW 71 M, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND SOLUTION PIPE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY		52% 54% 76%
MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA; GREY, SUBANGULAR CARBONATE INCLUSIONS IN CALCAREOUS CLAY MATRIX, SOME SOLUTION FEATURES	DISTURBED BRECCIATED TEXTURE	WIDELY SPACED RANDOM TENSION/DESSICATION FRACTURES, FRACTURE AND SOLUTION VOID PERMEABILITY	LOW INTERPARTICLE AND FRACTURE POROSITY, MODERATE SOLUTION VOID POROSITY		77%
MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, WELL INDURATED, HEAVY BITUMEN STAIN	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		58% 62% 72%
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA	MARBLY TO FINELY INTERBEDDED (C?) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		33% 81%

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 157	GROUND ELEVATION: 323.20 MASL
COREHOLE LOCATION: 10-13-94-10W4	DATE LOGGED: SEPTEMBER 4,1981

DEPTH METRES	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
61.5	NON-MARINE	NON-CALCAREOUS CLAY					
62.0 – 63.0	MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, BIOLITHIC TEXTURE, WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN, ABUNDANT FAUNA, UNDISTURBED	MOUNDED, BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, BIOMOLDIC AND FRACTURE PERMEABILITY	VERY HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
63.5 – 68.5	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, LIGHT BITUMEN STAIN, SOME FAUNA, OCC. BIOSPARITIC HARDGROUND	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL AND RANDOM FRACTURES, EXTENSIVE BOUDINAGE, POTENTIAL ANISOTROPIC PERMEABILITY, MINOR WEATHERING ALONG FRACTURES	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
69.0 – 73.5	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY TO WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, SPARITIC HARDGROUND SURFACE AT 68.7 M ------- ------ ------ ------ HIGHLY ARGILLACEOUS BELOW 73 M	FINELY INTERBEDDED (CM) SHALE/LIMESTONE BELOW 68 M	BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
74.0 – 77.5	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY TO WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MARBLY TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY AFFORDED	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	001	
	MARINE	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED	LAMINAE	SUBHORIZONTAL TENSION FRACTURES	VERY LOW POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 188	GROUND ELEVATION: 314.29 MASL
COREHOLE LOCATION: 7-14-94-10W4	DATE LOGGED: AUGUST 6,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (FOOTAGE CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
31.7 32.4 33.1 33.8 34.5 35.2 35.9			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, OCC. BIOSPARITIC ZONE, BITUMEN STAIN, SOME PYRITE, WEATHERED UPPER 0.6 M (DISCOLORED)	MARBLY TO NODULAR MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL/RANDOM FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		67%
36.6 37.3 38.0			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE; OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A
38.7 39.4 40.1 40.8 41.5 42.2 42.9 43.6 44.3 45.0 45.7 46.4 47.1 47.8 48.5 49.2			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN PREDOMINATES IN VERTICAL FRACTURES, SOME FAUNA, TRACE OF PYRITE, HIGHLY ARGILLACEOUS BELOW 40.5 M (LAMINAE)	MARBLY TO NODULAR MICRITIC TEXTURE, SOME FINELY INTERBEDDED SHALE/LIMESTONE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED SUBVERTICAL/RANDOM FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		43% 45% 61%

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 181	GROUND ELEVATION: 317.00 MASL
COREHOLE LOCATION: 9-14-94-10W4	DATE LOGGED: AUGUST 8,1981

Depth (metres): 54.7, 55.4, 56.1, 56.8, 57.5, 58.2, 58.9, 59.6, 60.3, 61.0, 61.7, 62.4, 63.1, 63.8, 64.5, 65.2, 65.9, 66.6, 67.3, 68.0, 68.7, 69.4, 70.1

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
MARINE PLATFORM (CARBONATE)	CALCAREOUS SHALE GRADES TO ARGILLACEOUS LIMESTONE; GREY, FISSILE, WELL CEMENTED (HARD), SOME WEATHERING (DISCOLORATION); LIMESTONE IS WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOLUTION PIPETO 58.0	FISSILE SHALE, LIMESTONE IS NODULAR TO FINELY INTERBEDDED	SOLUTION FEATURES TO 58.0 M, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE AND SOLUTION PIPE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE SOLUTION VOID AND FRACTURE POROSITY		N/A
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME SOLUTION FEATURES (PIPE), BITUMEN STAIN, FINELY INTERBEDDED SHALES ARE FISSILE, PYRITIC, WELL CEMENTED, SOME BIOLITHIC ZONES	MARBLY TO NODULAR MICRITIC TEXTURE, SOME FINELY INTERBEDDED SHALES	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SOLUTION FEATURES IN UPPER 2 M (INTRAFORMATIONAL UNCONFORMITY), FRACTURE AND SOLUTION PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY		075 738 836

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 182	GROUND ELEVATION: 311.37 MASL
COREHOLE LOCATION: 11-14-94-10W4	DATE LOGGED: AUGUST 6, 1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
31.7 32.4			NON-MARINE	NON-CALCAREOUS SHALE; GREY, MASSIVE, POORLY CEMENTED		RANDOM DESSICATION FRACTURES			
33.1 33.8 34.5 35.2 35.9 36.6 37.3 38.0 38.7			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, OCC. PYRITE NODULE, SOME FAUNA, SOME RECRYSTALLIZED CALCITE, SLIGHTLY WEATHERED, SOME RUBBLY PACKSTONE TEXTURES	NODULAR TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND BIOMOLDIC POROSITY	N/A	
39.4 40.1 40.8 41.5 42.2 42.9 43.6 44.3 45.0 45.7 46.4 47.1 47.8 48.5				GRADES TO MARBLY MICRITIC TEXTURE BELOW 38 M				888 886 343 571 775	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 103	GROUND ELEVATION: 318.82 MASL
COREHOLE LOCATION: 10-14-94-10W4	DATE LOGGED: JULY 15,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (ROCKS CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
43.7 – 44.4			NON-MARINE	NON-CALCAREOUS CLAY, OLIVE, FISSILE, MODERATELY CEMENTED, SOME LAMINATIONS					
44.4 – 60.5			MARINE PLATFORM (CARBONATE)	GRADES TO ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME PYRITE, SOME FAUNA, WELL BEDDED AT 48 M, SHALY AT 52 M, MARBLY TEXTURE BELOW 54M	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE, HARDGROUND AT 54M	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SOLUTION, FRACTURE PERMEABILITY (ANISOTROPIC)	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		308, 413, 728, 415, 743

Depth marks (metres): 43.7, 44.4, 45.1, 45.8, 46.5, 47.2, 47.9, 48.6, 49.3, 50.0, 50.7, 51.4, 52.1, 52.8, 53.5, 54.2, 54.9, 55.6, 56.3, 57.0, 57.7, 58.4, 59.1, 59.8, 60.5

DEVONIAN WATERWAYS FORMATION

COREHOLE NO: 184

COREHOLE LOCATION: 14-24-94-10W4

DESCRIPTIVE COREHOLE LOG

GROUND ELEVATION: 318.[illegible] M.A.S.L.

DATE LOGGED: JULY [illegible] 198[illegible]

DEPTH (METRES): 52.2, 53.4, 54.6, 55.8, 57.0, 58.2, 59.4, 60.6, 61.8, 63.0, 64.2, 65.4, 66.6, 67.8, 69.0, 70.2, 71.4, 72.6, 73.8, 75.0, 76.2, 77.4, 78.6, 79.8, 81.0, 82.2, 83.4, 84.6, 85.8, 87.0, 88.2, 89.4, 90.6

Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
NON-MARINE	SAND/CLAY: DK.BROWN, BEDDED, NON-CALCAREOUS		DESSICATION FRACTURES			
NON-MARINE	CLAY: BROWN, MASSIVE, DESSICATED, NON-CALCAREOUS					
NON-MARINE	CLAY/SAND: GREY TO OLIVE, MASSIVE (SOME INTERBEDDED MEDIUM GRAINED SAND STRINGERS), DESSICATED	BEDDING				
MARINE PLATFORM	LIMESTONE INTRACLAST BRECCIA: WHITE TO GREY SUBANGULAR LIMESTONE INCLUSIONS IN GREY CALCAREOUS CLAY MATRIX, DISTURBED (SLUMPED) BEDDING, PLASTIC DEFORMATION OF CLAY MATRIX, BITUMEN STAIN, SOME FAUNA	DISTURBED (SLUMPED) BEDDING, BRECCIATED TEXTURE	BOUDINAGE, WIDELY SPACED RANDOM DESSICATION/COMPRESSION (?) FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
MARINE PLATFORM	LIMESTONE/CLAY: WHITE LIMESTONE FRAMEWORK, DK.BROWN CLAY MATRIX	DISTURBED MARLY TEXTURE			N/A	
MARINE PLATFORM (CARBONATE)	GRADES TO ARGILLACEOUS LIMESTONE: WHITE TO GREY MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME SOLUTION FEATURES, SOME PYRITE NODULES, UNDISTURBED	FINELY INTERBEDDED (CM) LIMESTONE/SHALE	KARST SOLUTION FEATURES, SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY	N/A	

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DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 185	GROUND ELEVATION: 315.28 MASL
COREHOLE LOCATION: 5-25-94-10W4	DATE LOGGED: JULY 8,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (FORMING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
46.7 47.4 48.1 48.8 49.5 50.2 50.9			NON-MARINE	LAMINATED CLAY/SILT: GREY, FISSILE, WELL CEMENTED (NON-CALCAREOUS), SOME SAND INTERBEDS, OCC. BITUMINOUS STRINGER, CARBONACEOUS PARTICLES, OCC. PYRITE NODULE	LAMINAE, SOME INTERBEDDED SANDY HORIZONS, SOME BITUMINOUS STRINGERS	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME WEATHERING, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
51.6 52.3			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: GREY, BIOLITHIC TEXTURE, WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL [illegible] FRACTURES, FRACTURE AND PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
53.0 53.7 54.4 55.1 55.8 56.5 57.2 57.9 58.6 59.3 60.0 60.7 61.4 62.1 62.8 63.5 64.2 64.9 65.6 66.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME HIGHLY ARGILLACEOUS HORIZONS, BITUMEN STAIN	MARLY TO FINELY INTERBEDDED (ON MICRITIC TEXTURES	[illegible] SPACED SUBHORIZONTAL/SUBVERTICAL FRACTURES; SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION

COREHOLE NO. 166

COREHOLE LOCATION: 7-25-94-10W4

DESCRIPTIVE COREHOLE LOG

GROUND ELEVATION: 318.8 MASL

DATE LOGGED: JULY 9, 1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (MISSING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
54.5									
55.0, 55.5, 56.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE, SOME FAUNA, SOME WEATHERING (DISCOLORATION)	MARBLY TO FINELY INTERBEDDED (C?) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		67% --- --- --- 75%
56.5, 57.0, 57.5			MARINE PLATFORM (SUPRATIDAL)	COQUINA; WHITE, POORLY CEMENTED (FRIABLE), BIOLITHIC FRAMEWORK, SPARITIC MATRIX, WELL BEDDED, HEAVY BITUMEN STAIN	WELL BEDDED		HIGH INTERPARTICLE AND BIOMOLDIC POROSITY		
58.0, 58.5, 59.0			MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA					
59.5, 60.0, 60.5			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, BIOLITHIC TEXTURE, SOME OLIVE CLAY INTERBEDS, HEAVY BITUMEN STAIN	MOUNDED, BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY		80%
61.0			NON-MARINE	CLAY/SAND; OLIVE, WELL BEDDED, POORLY CEMENTED, HEAVY BITUMEN SATURATION	BEDDING, SOME LAMINAE		MODERATE INTERPARTICLE POROSITY		
61.5, 62.0, 62.5, 63.0, 63.5, 64.0, 64.5, 65.0, 65.5, 66.0, 66.5, 67.0, 67.5, 68.0, 68.5, 69.0, 69.5, 70.0, 70.5			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME BIOLITHIC HARDGROUND SURFACES, OCC. RUBBLY ZONE	MARBLY TO FINELY INTERBEDDED (C?) MICRITIC TEXTURE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL/RANDOM COMPRESSION (?) FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY		90%

DEVONIAN WATERWAYS FORMATION

COREHOLE NO: 100

COREHOLE LOCATION: 8-26-94-10W4

DESCRIPTIVE COREHOLE LOG

GROUND ELEVATION: 311.93 MASL

DATE LOGGED: JULY 8, 1981

Depth (metres): 37.7, 38.4, 39.1, 39.8, 40.5, 41.2, 41.9, 42.6, 43.3, 44.0, 44.7, 45.4, 46.1, 46.8, 47.5, 48.2, 48.9, 49.6, 50.3, 51.0, 51.7, 52.4, 53.1, 53.8, 54.5, 55.2, 55.9, 56.6, 57.3, 58.0, 58.7, 59.4, 60.1

Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
NON-MARINE	LAMINATED CLAY SHALE, GREY, FISSILE, WELL CEMENTED NON-CALCAREOUS, SUBHORIZONTAL ATTITUDE, SOME OXIDATION STAIN	LAMINAR TO FINELY INTERBEDDED TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
NON-MARINE	SAND/SILT, OLIVE TO GREY, MEDIUM/COARSE GRAINED, MASSIVE, UNCEMENTED (FRIABLE)	MASSIVE				
MARINE PLATFORM (CARBONATE)	LIMESTONE INTRACLAST BRECCIA, GREY, SUBANGULAR LIMESTONE INCLUSIONS IN OLIVE SANDY CLAY MATRIX, DISTURBED SLUMPED BEDDING, BITUMEN STAIN	DISTURBED BEDDING, BRECCIATED TEXTURE	WIDELY SPACED, SUBHORIZONTAL/RANDOM FRACTURES, FRACTURE PERMEABILITY	MODERATE INTERPARTICLE AND FRACTURE POROSITY	N/A	
NON-MARINE	BITUMINOUS SAND BRECCIA, SUBANGULAR LIMESTONE INCLUSIONS IN MEDIUM GRAINED QUARTZ SAND MATRIX, HEAVY BITUMEN STAIN					
MARINE PLATFORM (CARBONATE)	BIOHERMAL LIMESTONE, WHITE, OOLITHIC TEXTURE, WELL INDURATED (VERY HARD), SOME RUBBLY ZONES, HEAVY BITUMEN STAIN	ROUNDED OOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME RANDOM FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	GRADES TO ARGILLACEOUS LIMESTONE, GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SHALE INTERBEDS BELOW 54 M, BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (ON MICRITIC TEXTURE	EXTENSIVE BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. RUBBLY ZONE (POTENTIAL COLLAPSE BRECCIA), FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	MODERATE FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 109	GROUND ELEVATION: 307.45 MASL
COREHOLE LOCATION: 1-30-94-9W4	DATE LOGGED: JULY 8,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (RECORDING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD	
44.7 45.4 46.1 46.8 47.5 48.2 48.9 49.6			NON-MARINE	NON-CALCAREOUS SHALE; GREY, FISSILE, MODERATELY WELL CEMENTED BANDS, SOME INTERLAMINATED BITUMINOUS BANDS, BEDDING CONVOLUTIONS, SOME CARBONACEOUS PARTICLES	LAMINAR TO FINELY INTERBEDDED (CM) CLAY/SAND	SOME BEDDING CONVOLUTIONS, WIDELY SPACED SUBHORIZONTAL FRACTURES, FRACTURE AND INTERPARTICLE PERMEABILITY	MODERATE INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
50.3 51.0 51.7 52.4 53.1 53.8 54.5 55.2 55.9 56.6 57.3 58.0 58.7 59.4 60.1 60.8 61.5 62.2 62.9 63.6 64.3 65.0			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODA), BITUMEN STAIN, OCC. BIOSPARITIC ZONE	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 170	GROUND ELEVATION: 300.92 MASL
COREHOLE LOCATION: 8-27-94-10W4	DATE LOGGED: JULY 9,1981

DEPTH (METRES)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	RQD
35.6–41.0	MARINE PLATFORM (CARBONATE)	WEATHERED CLAY SHALE GRADES TO INTERBEDDED ARGILLACEOUS LIMESTONE: OLIVE, MASSIVE, WELL CEMENTED NON-CALCAREOUS SHALE GRADES TO GREY, WELL INDURATED (VERY HARD), WELL BEDDED LIMESTONE, SOME SPHAEROSIDERITES, BITUMEN STAIN, SOME FAUNA	SOME LAMINATIONS, SUBHORIZONTAL BEDDING IN THE LIMESTONE UNIT	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	73%, 38%, 16%, 58%
41.0–44.0	MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: WHITE, BIOLITHIC TEXTURE, WELL INDURATED (VERY HARD), SOME RECRYSTALLIZED CALCITE	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	72%, 63%
44.0–51.2	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SMALL (1 CM WIDE) SOLUTION PIPE BELOW 49 M, INFILLED WITH SANDY BROWN CLAY, WEATHERED RIM	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, SOME KARST SOLUTION FEATURES, SOME WEATHERING, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY	40%, 71%, 40%

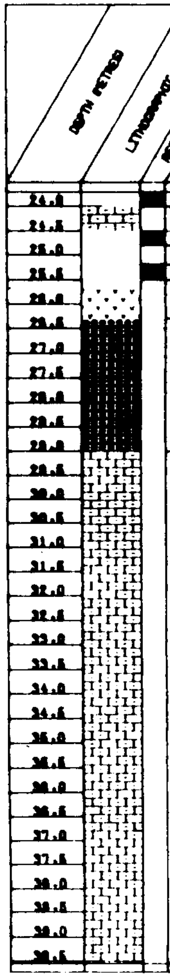
Depth scale (metres): 35.6, 36.2, 36.8, 37.4, 38.0, 38.6, 39.2, 39.8, 40.4, 41.0, 41.6, 42.2, 42.8, 43.4, 44.0, 44.6, 45.2, 45.8, 46.4, 47.0, 47.6, 48.2, 48.8, 49.4, 50.0, 50.6, 51.2

Other column headings: LITHOGRAPHIC SYMBOL; RECOVERY (CORING)/COREHOLE; PHOTOGRAPHIC PLATE

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 171	GROUND ELEVATION: 383.17 MASL
COREHOLE LOCATION: 6-27-94-10W4	DATE LOGGED: JULY 10,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
46.6									
47.2 47.8 48.4 49.0 49.6 50.2 50.8 51.4 52.0 52.6 53.2 53.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE NODULES, SOME FAUNA (BRACHIOPODS),BITUMEN STAIN	FINELY INTERBEDDED LIMESTONE/SHALE, SOME SHALY STRINGERS (CALCAREOUS)	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	073	
54.4 55.0 55.6 56.2			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), OCC. HARD (SPARITIC) HARDGROUND SURFACE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY		N/A	
56.8 57.4 58.0 58.6 59.2 59.8			MARINE PLATFORM (CARBONATE)	GRADES TO ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	FINELY INTERBEDDED LIMESTONE/SHALE TEXTURE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
60.4 61.0 61.6 62.2 62.8			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 172	GROUND ELEVATION: 292.44 MASL
COREHOLE LOCATION: 11-27-94-10W4	DATE LOGGED: JULY 7, 1981



SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
[illegible]	ARGILLACEOUS LIMESTONE; WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MARBLY TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRAC. PERM.			
	CALCAREOUS CLAY; OLIVE, MASSIVE					
[illegible]	LIMESTONE INTRACLAST BRECCIA; GREY, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS CLAY MATRIX	MASSIVE	WIDELY SPACED RANDOM DESSICATION FRACTURES			
[illegible]	BIOHERMAL LIMESTONE; WHITE, WELL INDURATED, HEAVY BITUMEN STAIN	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOHERMAL PERMEABILITY	HIGH BIOMOLDIC POROSITY LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME OLIVE CLAY INTERBEDS, BITUMEN STAIN IN VERTICAL FRACTURES, SOME FAUNA (BRACHIOPODS)	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE, SOME CLAY INTERBEDS	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, EXTENSIVE BOUDINAGE, WIDELY SPACED SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 173	GROUND ELEVATION: 301.71 MASL
COREHOLE LOCATION: 10-27-94-10W4	DATE LOGGED: JULY 8,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY POSSIBLE CORD	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
36.7										
37.4			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY TO WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA (BRACHIOPODS, ETC.), PYRITE NODULE, BIOSPARITIC ZONE AT 40.7 M, KARST SOLUTION PIPE AT 43-44 M, SAND STRINGER AT 37.0	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL/SUBVERTICAL FRACTURES, FRACTURE AND SOLUTION PIPE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND SOLUTION PIPE POROSITY		N/A	
38.1										
38.8										
39.5										
40.2										
40.9										
41.6										
42.3										
43.0										
43.7										
44.4										
45.1										
45.8										
46.5			MARINE PLATFORM (CARBONATE)	GRADES TO FINELY INTERBEDDED LIMESTONE/SHALE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	FINELY INTERBEDDED (CM) LIMESTONE/SHALE, SOME LAMINAE	EXTENSIVE BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
47.2										
47.9										
48.6										
49.3										
50.0										
50.7										
51.4			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE; OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
52.1										
52.8										
53.5										

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 174	GROUND ELEVATION: 288.9 MASL
COREHOLE LOCATION: 3-34-94-18W4	DATE LOGGED: JUNE 12,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (FORMING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
30.6 31.2 31.8 32.4 33.0 33.6 34.2			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), BITUMEN STAIN, SLIGHT WEATHERING (DISCOLORATION)	MARBLY MICRITIC TEXTURE, SOME FINELY INTERBEDDED SHALE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, MINOR SOLUTION FEATURES, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY		N/A
34.8			MARINE (SHALE)	GRADES TO CALCAREOUS SHALE; OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	FINELY LAMINATED	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
35.4 36.0 36.6 37.2 37.8 38.4 39.0 39.6 40.2			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE,SUBVERTICAL SOLUTION PIPE, GRADES TO CALCAREOUS SHALE	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOLUTION PIPE AT 37.5 M (2-3 CM WIDE, SUBVERTICAL, LT. GREEN, CLAY/LIMESTONE BRECCIA INFILLING), FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY		N/A
40.8 41.4 42.0 42.6 43.2 43.8 44.4 45.0 45.6 46.2			MARINE PLATFORM (CARBONATE)	GRADES TO ARGILLACEOUS LIMESTONE AT 40.5 M; OLIVE TO GREY, MICROCRYSTALLINE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS)	MARBLY TO NODULAR TO FINELY INTERBEDDED(CM) MICRITIC TEXTURE, SOME SPARITIC HARDGROUND SURFACES	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 175	GROUND ELEVATION: 282.36 MASL
COREHOLE LOCATION: 5-34-94-18W4	DATE LOGGED: JULY 28,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (DISCING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
15.7 16.4 17.1 17.8 18.5 19.2			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, BIOLITHIC TEXTURE, WELL INDURATED (HARD), HEAVY BITUMEN STAIN, ABUNDANT FAUNA, SOME RECRYSTALLIZED CALCITE, WEATHERING DISCOLORATION IN UPPER 0.8	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, BIOMOLDIC AND FRACTURE PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	886 856 479	
19.9 20.6 21.3 22.0 22.7 23.4 24.1 24.8 25.5			MARINE PLATFORM (CARBONATE)	GRADES TO INTERBEDDED LIMESTONE/SHALE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WI[illegible]LY SPACED SUBHORIZONTAL [illegible] FRACTURES, SOME BOUDINAGE, [illegible] AND SOLUTION VOID [illegible]LITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	806 541 843 738	
26.2 26.9 27.6 28.3 29.0 29.7			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, MINOR WEATHERING, SOLUTION PIPE AT 25.3M	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY	585 861	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 177	GROUND ELEVATION: 288.15 MASL
COREHOLE LOCATION: 10-34-94-10W4	DATE LOGGED: JULY 9, 1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (ROCKING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
43.7 – 44.4			NON-MARINE	SANDY CLAY: GREY, FISSILE, NON-CALCAREOUS, SOME SANDY STRINGERS, BITUMEN STAIN	LAMINAE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES			
44.4 – 59.1			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL INDURATED (HARD), SUBHORIZONTAL ATTITUDE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS	LAMINAE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS	SOME BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY		N/A
59.1 – 61.2			MARINE PLATFORM (CARBONATE)	LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, LOW ARGILLACEOUS CONTENT, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS)	MARBLY TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		79%

Depth scale (metres): 43.7, 44.4, 45.1, 45.8, 46.5, 47.2, 47.9, 48.6, 49.3, 50.0, 50.7, 51.4, 52.1, 52.8, 53.5, 54.2, 54.9, 55.6, 56.3, 57.0, 57.7, 58.4, 59.1, 59.8, 60.5, 61.2

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 170	GROUND ELEVATION 300.00 MASL
COREHOLE LOCATION 1-35-94-10W4	DATE LOGGED JUNE 29,1981

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA, GREY, SUBANGULAR LIMESTONE INCLUSIONS IN CALCAREOUS CLAY MATRIX, WELL INDURATED (VERY HARD), BITUMEN STAIN, SOME WEATHERING ALONG FRACTURES	DISTURBED BRECCIATED TEXTURE	MODERATELY SPACED RANDOM FRACTURES, DESICCATION FRACTURES, MINOR WEATHERING, FRACTURE PERMEABILITY	MODERATE INTERPARTICLE AND FRACTURE POROSITY	N/A	
MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE, WHITE TO GREY, BIOLITHIC TEXTURE, WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN, ABUNDANT FAUNA, MINOR SOLUTION FEATURES	MOUNDED BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, MINOR SOLUTION FEATURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE AND SOLUTION VOID POROSITY	N/A	
MARINE? PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODA, ETC.), SANDY STRINGERS, SOME BIOSPARITIC ZONES, BITUMEN STAIN IN VERTICAL FRACTURES	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN IN SUBVERTICAL FRACTURES, SOME SANDY STRINGERS, PYRITE IN SHALY SECTIONS ——— ——— FINELY INTERBEDDED AT [illegible] M	FINELY INTERBEDDED (CM) LIMESTONE/SHALE	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEPTH (METRES): 48.5, 49.0, 49.5, 50.0, 50.5, 51.0, 51.5, 52.0, 52.5, 53.0, 53.5, 54.0, 54.5, 55.0, 55.5, 56.0, 56.5, 57.0, 57.5, 58.0, 58.5, 59.0, 59.5, 60.0, 60.5, 61.0, 61.5, 62.0, 62.5, 63.0, 63.5

LITHOGRAPHIC SYMBOL

RECOVERY (PERCENT CORE)

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 179	GROUND ELEVATION: 388.84 MASL
COREHOLE LOCATION: 3-35-94-18W4	DATE LOGGED: JUNE 29,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (BOXING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
45.7 46.4 47.1 47.8 48.5 49.2 49.9 50.6 51.3 52.0 52.7 53.4 54.1 54.8 55.5 56.2 56.9 57.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, OCC. BIOSPARITIC ZONE, SOME BITUMEN STAIN, ABUNDANT FAUNA (BRACHIOPODS)	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE, BIOSPARITIC ZONE AT 54.4 M	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
58.3 59.0 59.7			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE, OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS, UNDISTURBED	LAMINAE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 180	GROUND ELEVATION: 302.33 MASL
COREHOLE LOCATION: 14-35-94-10W4	DATE LOGGED: JULY 13,1981

DEPTH (METRES): 45.7, 46.4, 47.1, 47.8, 48.5, 49.2, 49.9, 50.6, 51.3, 52.0, 52.7, 53.4, 54.1, 54.8, 55.5, 56.2, 56.9, 57.6, 58.3, 59.0, 59.7, 60.4, 61.1, 61.8, 62.5, 63.2, 63.9, 64.6, 65.3, 66.0

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (SHALE)	NON-MARINE BITUMINOUS BAND CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT PYRITE	MASSIVE LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	855 853	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), SOME PYRITE NODULES	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	985 835 836	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 101	GROUND ELEVATION: 306.14 MASL
COREHOLE LOCATION: 10-35-94-10W4	DATE LOGGED: AUGUST 17,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY POSSIBLE CORED	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
[illegible], 35.5, 36.3, 37.0, 37.8, 38.5, 39.3, 40.0, 40.8, 41.5, 42.3, 43.0, 43.8, 44.5			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, MODERATELY WEATHERED IN UPPER 0.5 M, TRACE OF FAUNA, BITUMEN STAIN, GRADES TO CALCAREOUS SHALE BELOW 40 M	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE, SOME LAMINATIONS IN SHALY HORIZON	SOME BOUDINAGE, WEATHERED UPPER 0.5 M, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	
45.3, 46.0, 46.8, 47.5, 48.3, 49.0, 49.8, 50.5, 51.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED, SUBHORIZONTAL ATTITUDE, GRADES TO CALCAREOUS SHALE AT 47 M GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE, SOME LAMINAE	SOME BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL COMPRESSION FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 102	GROUND ELEVATION: 312.91 MASL
COREHOLE LOCATION: 6-30-94-10W4	DATE LOGGED: AUGUST 13,1981

Depth (metres): 49.0, 50.3, 50.8, 51.0, 52.2, 52.8, 53.6, 54.2, 54.8, 55.6, 56.1, 56.8, 57.4, 58.1, 58.7, 59.4, 60.0, 60.7, 61.3, 62.0, 62.[illegible], 63.[illegible], 63.8, 64.0

Depth Metres	Lithographic Symbol	Recovery (Missing Core)	Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA, SOME BIOSPARITIC HARDGROUND SURFACES	FINELY INTERBEDDED WAVY TO PLANAR CONTACTS	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. INCLINED COMPRESSION (?) FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE AND BIOMOLDIC POROSITY	085, 028, 035, 341	
			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOLUTION PIPE INFILLED WITH CLAY/LIMESTONE BRECCIA AT 55 M, MINOR CALCITE RECRYSTALLIZATION	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOLUTION FEATURES (PIPE), FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY	343, 084	
			MARINE PLATFORM (BIOHERMAL)	LIMESTONE INTRACLAST BRECCIA: GREY, SUBANGULAR LIMESTONE INCLUSIONS IN DK. BROWN CALCAREOUS CLAY MATRIX, WELL CEMENTED (HARD), BITUMEN STAIN	DISTURBED, BRECCIATED TEXTURE, TRACE OF BEDDING	SOME BOUDINAGE, MODERATELY SPACED RANDOM FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
			MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE: DK.GREY TO WHITE, BIOLITHIC TEXTURE, MODERATELY WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN, SOME RECRYSTALLIZED CALCITE, POTENTIAL BRECCIATED (COLLAPSE) ZONE AT 63.1 - 63.4 M	MOUNDED, BIOLITHIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	085, 205	

DEVONIAN WATERWAYS FORMATION

COREHOLE NO: 103

COREHOLE LOCATION: [illegible]-38-94-1 W4

DESCRIPTIVE COREHOLE LOG

GROUND ELEVATION: 315.97 MASL

DATE LOGGED: AUGUST 13, 1981

DEPTH (METRES)	LITHOLOGIC SYMBOL	RECOVERY (PERCENT CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
[illegible]			[illegible]	[illegible] LIMESTONE, BUFF TO WHITE, [illegible], WELL [illegible] MARK, SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	[illegible] MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
			[illegible]	[illegible] SAND, BUFF, [illegible], POORLY CEMENTED [illegible], WELL [illegible], PHYSICALLY/CHEMICALLY [illegible]	MASSIVE		[illegible] INTERPARTICLE POROSITY	N/A	
			[illegible]	[illegible] LIMESTONE, WHITE, MICROCRYSTALLINE, WELL [illegible], SUBHORIZONTAL ATTITUDE, SOLUTION [illegible] AT 60.2 AND 65 M [illegible], [illegible]/SAND/CLAY INFILLING, BITUMEN STAIN, SHALY SECTION AT 60	[illegible] TO FINELY INTERBEDDED (ON MICRITIC TEXTURES	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, EXTENSIVE SOLUTION FEATURES, FRACTURE AND SOLUTION VOID PERMEABILITY	MODERATE FRACTURE AND SOLUTION VOID POROSITY	N/A	
70.3 70.9 71.5 72.1 72.7 73.3 73.9 74.5 75.1			MARINE PLATFORM (CARBONATE)	CALCAREOUS SHALE GRADING TO FINELY INTERBEDDED LIMESTONE/SHALE AT 70 M, OLIVE TO GREY, FISSILE, WELL CEMENTED [illegible], SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, UNDISTURBED APPEARANCE, SHALY AT 74	LAMINAR TO FINELY INTERBEDDED (ON SOME NODULAR LIMESTONE TEXTURES	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 104	GROUND ELEVATION: 309.80 MASL
COREHOLE LOCATION: 12-30-94-10W4	DATE LOGGED: AUGUST 14,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
67.7									
[illegible]			[illegible]	ARGILLACEOUS LIMESTONE: WHITE TO BUFF WEATHERING, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA(BRACHIOPODA), WEATHERING IN UPPER 0.4 M DISCOLORED	MARBLY TO FINELY INTERBEDDED (C/M) MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, OCC. SUBVERTICAL COMPRESSION (?) FRACTURE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	[illegible] 775 776	
[illegible]				NON-CALCAREOUS SHALE: GREY TO OLIVE, FISSILE, WELL CEMENTED, SUBHORIZONTAL ATTITUDE	LAMINAE				
[illegible]			[illegible]	ARGILLACEOUS LIMESTONE: GREY TO WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA (BRACHIOPODA), SHALY AT [illegible], SMALL SOLUTION PIPE AT 69 M - CLAY/BRECCIA INFILLING	MARBLY TO FINELY INTERBEDDED (C/M) MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, EXTENSIVE BOUDINAGE, KARST SOLUTION FEATURES, FRACTURE AND SOLUTION VOID PERMEABILITY	MODERATE FRACTURE AND SOLUTION VOID POROSITY	[illegible]	
70.3									
71.0			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: GREY, SOME FISSILE HORIZONS, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, NUMEROUS LIMESTONE NODULES	LAMINAR TO NODULAR TEXTURES	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
71.7									
72.4									
73.1									

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 105	GROUND ELEVATION: 318.93 MASL
COREHOLE LOCATION: 14-30-94-10W4	DATE LOGGED: JULY 10,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (MISSING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
52.0 – 53.9			NON-MARINE	NON-CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SOME WEATHERING DISCOLORATION	LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
				SAND					
				LIMESTONE					
				BITUMINOUS SAND					
				CLAY SHALE					
55.5 – 71.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS), SOME SMALL SOLUTION PIPES, PYRITE, BITUMEN STAIN	MARBLY TO RUBBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURES	MODERATELY SPACED SUBHORIZONTAL [illegible] FRACTURES, FRACTURE [illegible]	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY	986 886 563 853 318	

Depth markers (metres): 52.0, 52.7, 53.4, 54.1, 54.8, 55.5, 56.2, 56.9, 57.6, 58.3, 59.0, 59.7, 60.4, 61.1, 61.8, 62.5, 63.2, 63.9, 64.6, 65.3, 66.0, 66.7, 67.4, 68.1, 68.8, 69.5, 70.2, 70.9, 71.6

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 108	GROUND ELEVATION: 307.4 MASL
COREHOLE LOCATION: 2-35-94-10W4	DATE LOGGED: JUNE 15, 1981

DEPTH (METRES)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
45.0, 46.0	NON-MARINE	CARBONACEOUS CLAY/SAND					
47.0, 48.0, 49.0, 50.0, 51.0, 52.0, 53.0, 54.0, 55.0	MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE TO GREY, MODERATELY INDURATED, INTERBEDDED MICROCRYSTALLINE LIMESTONE, INTRACLAST BRECCIA AT 48.1 M, DK. BROWN RUBBLY CLAY AT 50 M, BRECCIA AT 51.4 M, POTENTIAL UNCONFORMITIES AT 48.1, 55.0 M	MOUNDED BIOLITHIC TO MASSIVE MICROCRYSTALLINE TEXTURE	SOLUTION FEATURES, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES. FRACTURE, SOLUTION VOID AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, MODERATE FRACTURE/SOLUTION VOID POROSITY	N/A	
56.0, 57.0, 58.0, 59.0, 60.0, 61.0, 62.0, 63.0, 64.0, 65.0, 66.0	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HIGHLY FRACTURED (RUBBLY) AT 57-58M, BITUMEN STAIN, ABUNDANT FAUNA (BRACHIOPODS), SOME BRECCIA	MARBLY MICRITIC TO FINELY INTERBEDDED (CM) SHALE/LIMESTONE TEXTURES	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME INCLINED FRACTURES. MINOR SOLUTION FEATURES, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY	N/A	
67.0, 68.0, 69.0, 70.0, 71.0, 72.0	MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, BIOSPARITIC HARDGROUND AT 69.9 M, SOME FAUNA (BRACHIOPODS), FINELY INTERBEDDED LIMESTONE/SHALE AT 70 M	LAMINAE, SOME NODULAR LIMESTONE TEXTURES	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE. FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 107	GROUND ELEVATION: 311.44 MASL
COREHOLE LOCATION: 4-30-94-10W4	DATE LOGGED: JUNE 29,1981

Depth (metres): 55.7, 56.4, 57.1, 57.8, 58.5, 59.2, 59.9, 60.6, 61.3, 62.0, 62.7, 63.4, 64.1, 64.8, 65.5, 66.2, 66.9, 67.6, 68.3, 69.0, 69.7, 70.4, 71.1, 71.8, 72.5

Sedimentary Facies	Lithologic Description	Primary Structure	Secondary Structure	Porosity	Photographic Plate	RQD
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN	MARBLY TO FINELY INTERBEDDED (2) MICRITIC TEXTURE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SOLUTION CAVITIES, FRACTURE PERMEABILITY		N/A	
MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE, BIOLITHIC TEXTURE, MODERATELY WELL INDURATED (HARD), SOME PYRITE NODULES	MOUNDED BIOLITHIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE AND BIOMOLDIC PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	GRADES TO ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	FINELY INTERBEDDED (2) SHALE/LIMESTONE UNITS	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 100	GROUND ELEVATION: 315.1 MASL
COREHOLE LOCATION: 2-30-94-10W4	DATE LOGGED: JUNE 10,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (CORING CARD)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD	
45.7 46.4 47.1 47.8 48.5 49.2 49.9 50.6 51.3 52.0 52.7 53.4 54.1 54.8 55.5 56.2 56.9 57.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME SPARITIC STRINGERS (POTENTIAL HARDGROUND SURFACES), SLIGHT WEATHERING	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURES, SOME NODULAR LIMESTONE TEXTURES	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED SUBVERTICAL COMPRESSION (?) FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
58.3 59.0 59.7 60.4 61.1			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE; OLIVE, FISSILE, WELL CEMENTED (HARD), SOME FAUNA (BRACHIOPODS)	LAMINAE, SOME BLOCKY TEXTURES	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SUBVERTICAL COMPRESSION (?) FRACTURES, TRACE OF BOUDINAGE, FRACTURE PERMEABILITY (ANISOTROPIC)	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 198	GROUND ELEVATION: 319.41 MASL
COREHOLE LOCATION: 10-31-94-9W4	DATE LOGGED: AUGUST 18,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
68.7 – 70.1			MARINE PLATFORM (CARBONATE)	INTERBEDDED LIMESTONE/SHALE: GREY, FINELY INTERBEDDED TO FISSILE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE NODULES	FINELY INTERBEDDED TO LAMINAR (<0.5CM)	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
70.1 – 74.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	NODULAR TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A
74.3 – 84.1			MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE BELOW 73.7 m: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE NODULES, OCC. BRACHIOPOD, SLIGHT WEATHERING ALONG FRACTURES	LAMINAR	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME WEATHERING, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A

Depth scale (metres): 68.7, 69.4, 70.1, 70.8, 71.5, 72.2, 72.9, 73.6, 74.3, 75.0, 75.7, 76.4, 77.1, 77.8, 78.5, 79.2, 79.9, 80.6, 81.3, 82.0, 82.7, 83.4, 84.1

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 101	GROUND ELEVATION: 319.75 MASL
COREHOLE LOCATION: 10-32-94-SW4	DATE LOGGED: AUGUST 10, 1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (PERCENT CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
80.2 80.9			NON-MARINE	NON-CALCAREOUS SHALE: OLIVE, FISSILE, POORLY CEMENTED, WEATHERED (DISCOLORED)	LAMINAE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		N/A	
81.6 82.3 83.0 83.7 84.4 85.1 85.8			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN, SOME PYRITE NODULES, ABUNDANT FAUNA, INTERBEDDED SHALE AT 84 M, SHALY AT 85	MARLY MICRITIC TEXTURE, INTERBEDDED AT 84 M	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY		815 758	
86.5 87.2 87.9 88.6 89.3 90.0 90.7 91.4 92.1 92.8 93.5 94.2 94.9 95.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, EXTENSIVE SOLUTION FEATURES 10 CM WIDE PIPE INFILLED WITH CLAY/LIMESTONE COLLAPSE BRECCIA, HEAVY BITUMEN STAIN	MARLY MICRITIC TEXTURE, SHALY BELOW 94	MODERATELY SPACED SUBHORIZONTAL FRACTURES, DISTINCT WEATHERED ZONE IN PIPE WALL - FOLLOWED BY 3MM PYRITIC BAND, SMALLER (1CM) PIPES FORM ALONG JOINT FRACTURES - BITUMEN INFILTRATION FOLLOWED	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE AND SOLUTION VOID POROSITY		N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 192	GROUND ELEVATION: 320.46 MASL
COREHOLE LOCATION: 8-32-94-9W4	DATE LOGGED: AUGUST 18,1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (MISSING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
94.7 95.4 96.1 96.8 97.5 98.2 98.9 99.6 100.3 101.0			MARINE PLATFORM SHALE	CALCAREOUS SHALE: GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SUBVERTICAL/INCLINED FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
101.7 102.4 103.1 103.8 104.5 105.2			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, ABUNDANT FAUNA (BRACHIOPODS), PYRITE NODULES, WEATHERING ALONG FRACTURES (SOFT CLAY INFILLING), SHALY AT 104 M, UNDISTURBED	MARBLY TO NODULAR TEXTURE, SHALY BELOW 104 M, SOME LAMINAE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED SUBVERTICAL/INCLINED FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		653 715 585	
105.9 106.6 107.3 108.0 108.7 109.4 110.1 110.8 111.5 112.2			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE, UNDISTURBED	MARBLY TO NODULAR TEXTURE, SOME LAMINAE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		683 753 686 685	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 193	GROUND ELEVATION: 321.27 MASL
COREHOLE LOCATION: 13-29-94-W4	DATE LOGGED: JULY 6, 1981

DEPTH METRES	LITHOGRAPHIC SYMBOL	RECOVERY (RUBBING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
87.7										
88.4			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME FAUNA (BRACHIOPODS)	FINELY INTERBEDDED (CM) TEXTURE, SOME LAMINAE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
89.1										
89.8										
90.5										
91.2										
91.9										
92.6			MARINE PLATFORM (SHALE)	ARGILLACEOUS LIMESTONE GRADES TO CALCAREOUS SHALE BELOW 98 m GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HARD BIOLITHIC ZONE @ 92-94 m, SOME PYRITE, BITUMEN STAIN, FISSILE SHALE, WELL CEMENTED	NODULAR TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE, SHALES ARE LAMINAR	SOME BOUDINAGE, CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		N/A	
93.3										
94.0										
94.7										
95.4										
96.1										
96.8										
97.5										
98.2										
98.9										
99.6										
100.3										
101.0										
101.7										
102.4										

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 194	GROUND ELEVATION: 322.84 MASL
COREHOLE LOCATION: 4-29-94-8W4	DATE LOGGED: JULY 8,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (POROSITY CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
60.7									
61.4			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, MINOR WEATHERING, BITUMEN STAIN, SOME PYRITE NODULES	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
62.1									
62.8				GRADES TO FINELY INTERBEDDED LIMESTONE/SHALE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA, OCC. BIOSPARITIC ZONE, SOME PYRITE NODULES, SHALY BELOW 75 M (FISSILE, CALCAREOUS)	FINELY INTERBEDDED (CM) LIMESTONE/SHALE, SOME LAMINAE	SOME BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
63.5									
64.2									
64.9									
65.6									
66.3									
67.0									
67.7									
68.4									
69.1									
69.8			MARINE PLATFORM (CARBONATE)						
70.5									
71.2									
71.9									
72.6									
73.3									
74.0									
74.7									
75.4									
76.1									
76.8									

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 195	GROUND ELEVATION: 322.48 MASL
COREHOLE LOCATION: 7-29-94-9W4	DATE LOGGED: JULY 13,1981

DEPTH (METRES)	LITHOGRAPHIC SYMBOL	RECOVERY (MISSING CORE)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
79.7 80.4 81.1 81.8 82.5 83.2 83.9 84.6 85.3 86.0 86.7 87.4 88.1 88.8 89.5			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE NODULES	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME INCLINED COMPRESSION (?) FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	
90.2 90.9 91.6 92.3			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; WHITE TO GREY, MICROCRYSTALLINE, WELL CEMENTED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, SOME KARST SOLUTION FEATURES (PIPE), SOME PYRITE, ABUNDANT FAUNA	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME SOLUTION FEATURES, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
93.0 93.7 94.4 95.1 95.8			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE; GREY, FISSILE, WELL CEMENTED (HARD), SOME PYRITE, POTENTIAL SHEAR ZONE AT 96 M	LAMINAR TO FINELY INTERBEDDED (C?) LIMESTONE/SHALE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, WIDELY SPACED SUBVERTICAL COMPRESSION (?) FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO: 198	GROUND ELEVATION: 321.02 MASL
COREHOLE LOCATION: 10-29-94-8W4	DATE LOGGED: JULY 29,1981

DEPTH (METRES)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
55.7							
56.4 – 65.5 (56.4, 57.1, 57.8, 58.5, 59.2, 59.9, 60.6, 61.3, 62.0, 62.7, 63.4, 64.1, 64.8, 65.5)	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE: WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SOME SHALE STRINGERS, WEATHERING DISCOLORATION IN UPPER 1-2 M, SOME FAUNA (BRACHIOPODS), SOME RECRYSTALLIZED CALCITE	MARBLY TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	853, 853, 858, 845, 573	
66.2 – 69.0 (66.2, 66.9, 67.6, 68.3, 69.0)	MARINE PLATFORM (SHALE)	GRADES TO CALCAREOUS SHALE: OLIVE TO GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME LIMESTONE NODULES, GRADES TO INTERBEDDED LIMESTONE/SHALE AT 69	LAMINAE, SOME LIMESTONE NODULES	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, TRACE OF BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
69.7 – 71.1 (69.7, 70.4, 71.1)	MARINE PLATFORM (SHALE)	CALCAREOUS SHALE: OLIVE TO GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME LIMESTONE NODULES, WEATHERING ALONG FRACTURES	LAMINAE, SOME LIMESTONE NODULES	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE [illegible] 197	GROUND ELEVATION: 323.50 MASL
COREHOLE LOCATION: 4-20-94-9W4	DATE LOGGED: JUNE 9,1981

DEPTH (METRES): 68.7, 69.4, 70.1, 70.8, 71.5, 72.2, 72.9, 73.6, 74.3, 75.0, 75.7, 76.4, 77.1, 77.8, 78.5, 79.2, 79.9, 80.6, 81.3, 82.0, 82.7, 83.4, 84.1, 84.8, 85.5, 86.2, 86.9, 87.6, 88.3

DEPTH (METRES)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
69.4 – 81.3	MARINE PLATFORM (BIOHERMAL)	BIOHERMAL LIMESTONE; WHITE TO GREY, BIOLITHIC TEXTURE, WELL INDURATED (VERY HARD), HEAVY BITUMEN STAIN, SOME CARBONACEOUS PARTICLES, ABUNDANT FAUNA, GRADES TO INTERBEDDED ARGILLACEOUS LIMESTONE at 72	ROUNDED BIOLITHIC TEXTURE, SOME LAMINAE, FINELY INTERBEDDED (CM) SHALE/LIMESTONE AT 72 M	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME INCLINED COMPRESSION (?) FRACTURES, SOME SOLUTION FEATURES (PIPES), FRACTURE AND SOLUTION PIPE PERMEABILITY	HIGH BIOMOLDIC POROSITY, LOW FRACTURE POROSITY	N/A	
81.3 – 84.1	DISTURBED ZONE	LIMESTONE BRECCIA; FRAGMENTED LIMESTONE CLASTS, DISTURBED (SLUMPED) BEDDING PLANES, NUMEROUS SUBVERTICAL COMPRESSION FRACTURES, NO GOUGE, NO EVIDENCE OF SLICKENSIDES, SOME CALCITE RECRYSTALLIZATION IN VUGGY POROSITY, SOME PYRITE NODULES	DISTURBED BEDDING PLANES, MAINLY MICRITIC TEXTURES	POTENTIAL SOLUTION COLLAPSE FEATURE OR BRITTLE SHEAR ZONE	LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	
84.1 – 88.3	MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE; GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE	NODULAR TO FINELY INTERBEDDED (CM) MICRITIC TEXTURE	SOME BOUDINAGE, WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC)	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 100	GROUND ELEVATION: 325.74 MASL
COREHOLE LOCATION: 12-17-94-9W4	DATE LOGGED: SEPTEMBER 3, 1981

DEPTH (METRES): [illegible], 73.0, 73.5, 74.0, 74.5, 75.0, 75.5, 76.0, 76.5, 77.0, 77.5, 78.0, 78.5, 79.0, 79.5, 80.0, 80.5, 81.0, 81.5, 82.0, 82.5, 83.0, 83.5, 84.0, 84.5, 85.0, 85.5, 86.0, 86.5, 87.0, 87.5, 88.0, 88.5, 89.0

SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
NON-MARINE	CLAY, GREY, POORLY CEMENTED (FRIABLE), NON-CALCAREOUS, [illegible]					
[illegible]	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, SOME FAUNA (BRACHIOPODS)	MARBLY MICRITIC TEXTURE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	77B, 77A	
[illegible]	CALCAREOUS SHALE, GREY, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME LIMESTONE INTERBEDS	NODULAR TO FINELY INTERBEDDED TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
[illegible]	ARGILLACEOUS LIMESTONE, GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, [illegible] HARDGROUND AT 81.3-81.5	FINELY INTERBEDDED (CM) LIMESTONE/SHALE	[illegible]ATELY SPACED SUBHORIZONTAL [illegible]NSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
[illegible]	ARGILLACEOUS LIMESTONE; POTENTIAL HARDGROUND SURFACE AT 81.3 M					
MARINE PLATFORM (SHALE)	CALCAREOUS SHALE, GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME PYRITE, NON-FOSSILIFEROUS	LAMINAR TO FINELY INTERBEDDED (CM) LIMESTONE/SHALE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, EXTENSIVE BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	
MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, POTENTIAL HARDGROUND SURFACE AT 88.5 M, HIGHLY ARGILLACEOUS BELOW 87	MARBLY TO FINELY INTERBEDDED (CM) LIMESTONE/SHALE	WIDELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 190	GROUND ELEVATION: 325.38 MASL
COREHOLE LOCATION: 4-17-94-9W4	DATE LOGGED: SEPTEMBER 9, 1981

DEPTH (METRES)	LITHOLOGIC SYMBOL	RECOVERY (PERCENT CORED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY	PHOTOGRAPHIC PLATE	RQD
[illegible]			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN IN SUBVERTICAL FRACTURES, NON-FOSSILIFEROUS, SOME SIDERITE GRAINS, TRACE OF PYRITE, WEATHERING DISCOLOURATIONS IN UPPER 0.5 M	FINELY INTERBEDDED (CM) LIMESTONE/SHALE	EXTENSIVE BOUDINAGE, MODERATELY SPACED SUBHORIZONTAL/SUBVERTICAL FRACTURES, FRACTURE PERMEABILITY (POTENTIALLY ANISOTROPIC), WEATHERING IN UPPER 0.5 M	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	
[illegible]			MARINE PLATFORM SHALE	GRADES TO CALCAREOUS SHALE, GREY TO OLIVE, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE	LAMINAE	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE FRACTURE POROSITY	N/A	
[illegible]			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED (VERY HARD), SUBHORIZONTAL ATTITUDE, BITUMEN STAIN, TRACE OF PYRITE, HIGHLY ARGILLACEOUS BELOW 63	[illegible] TO FINELY INTERBEDDED (CM) LIMESTONE/SHALE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	
[illegible] – 70.0			MARINE PLATFORM SHALE	GRADES TO CALCAREOUS SHALE, GREY, FISSILE, WELL CEMENTED (HARD), SUBHORIZONTAL ATTITUDE, SOME FINELY INTERBEDDED LIMESTONE STRINGERS, SOME PYRITE, LIGHT BITUMEN STAIN, NON-FOSSILIFEROUS	LAMINAE, SOME FINELY INTERBEDDED (CM) LIMESTONE STRINGERS	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE AND FRACTURE POROSITY	N/A	

DEVONIAN WATERWAYS FORMATION	DESCRIPTIVE COREHOLE LOG
COREHOLE NO. 280	GROUND ELEVATION: 322.58 MASL
COREHOLE LOCATION: 1-13-94-10W4	DATE LOGGED: AUGUST 25, 1981

DEPTH METRES	LITHOLOGIC SYMBOL	SEDIMENT PERIODS (SED)	SEDIMENTARY FACIES	LITHOLOGIC DESCRIPTION	PRIMARY STRUCTURE	SECONDARY STRUCTURE	POROSITY		PHOTOGRAPHIC PLATE	RQD
75.7										
76.4, 77.1, 77.8, 78.5, 79.2, 79.9			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE TO GREY, MICROCRYSTALLINE, WELL INDURATED VERY HARD, SUBHORIZONTAL ATTITUDE, HEAVY BITUMEN STAIN IN VERTICAL FRACTURES, ABUNDANT FAUNA BRACHIOPODS, STROMS, CRINOIDS	NODULAR TO MARBLY MICRITIC TEXTURE, POORLY DEFINED BEDDING	CLOSELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, SOME INCLINED FRACTURES, SOLUTION FEATURES AT 80M, FRACTURE AND SOLUTION VOID PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, MODERATE BIOMOLDIC, FRACTURE AND SOLUTION VOID POROSITY		836, 888, 541	
80.6, 81.3, 82.0, 82.7, 83.4			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE, MICROCRYSTALLINE, WELL INDURATED VERY HARD, SUBHORIZONTAL ATTITUDE	MARBLY TO FINELY INTERBEDDED (OR MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, SOME BOUDINAGE, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		343	
84.1, 84.8, 85.5			MARINE [illegible]	LIMESTONE BRECCIA, SUBANGULAR LIMESTONE CLASTS IN OLIVE, CALCAREOUS CLAY MATRIX	DISTURBED BEDDING	COLLAPSE STRUCTURE			N/A	
86.2, 86.9, 87.6			MARINE PLATFORM (CARBONATE)	ARGILLACEOUS LIMESTONE, WHITE, MICROCRYSTALLINE, WELL INDURATED VERY HARD, SUBHORIZONTAL ATTITUDE, POTENTIAL HARDGROUND AT 86.5	MARBLY TO FINELY INTERBEDDED (OR MICRITIC TEXTURE	MODERATELY SPACED SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY			
88.3, 89.0, 89.7, 90.4, 91.1			MARINE PLATFORM (SHALE)	CALCAREOUS SHALE, GREY, FISSILE, WELL CEMENTED HARD, SUBHORIZONTAL ATTITUDE, SOME FAUNA BRACHIOPODS, POTENTIAL HARDGROUND SURFACE AT 90	LAMINAE, SOME NODULAR LIMESTONE TEXTURES	SOME BOUDINAGE, HIGH DENSITY SUBHORIZONTAL TENSION FRACTURES, FRACTURE PERMEABILITY	VERY LOW INTERPARTICLE POROSITY, LOW FRACTURE POROSITY		486	

APPENDIX B

(map pocket)

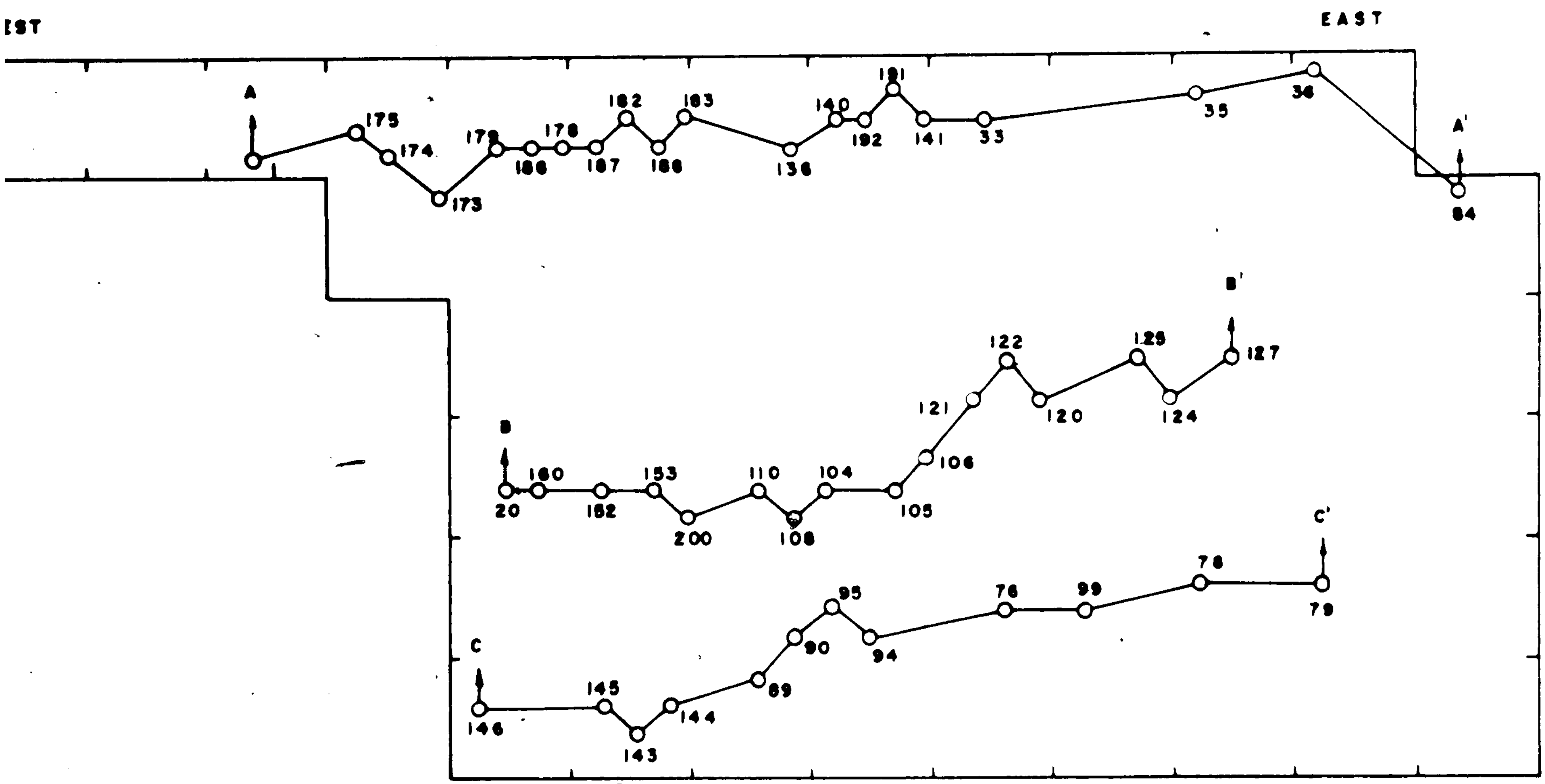


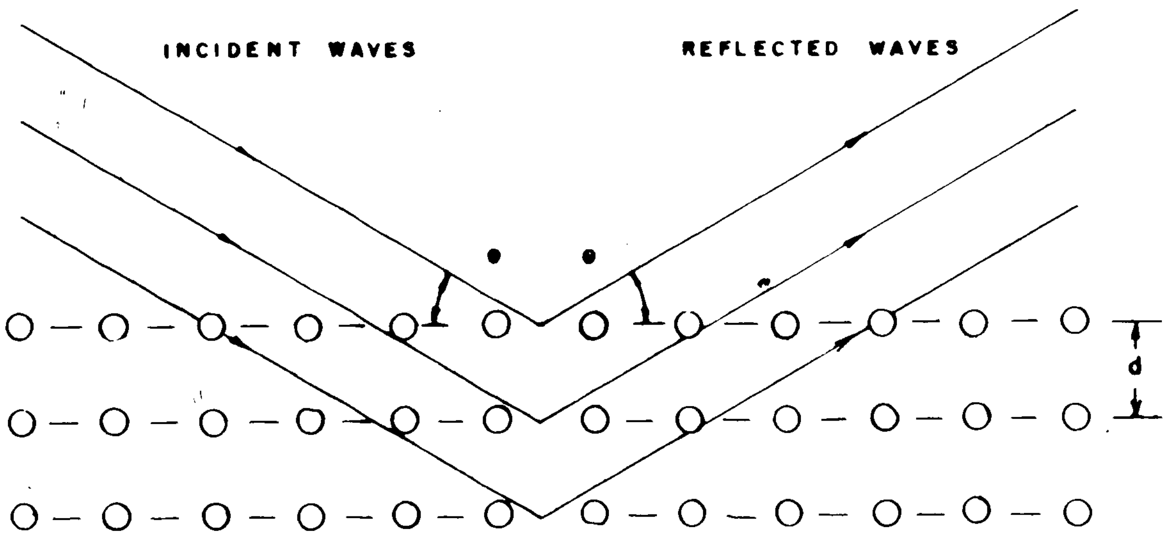
FIGURE B.1: STRATIGRAPHIC CROSS SECTION LOCATIONS

APPENDIX C

APPENDIX C - X-RAY DIFFRACTION TESTS

The diffraction of high speed electrons by planes of atoms is dictated by Bragg's Law which relates the angle of diffraction (θ) to the spacing (d) of atomic planes comprising the crystal structure of the examined mineral (Figure C.1). Subsequent back-calculation of d-spacing from diffraction traces permits the identification of various clay species. Moreover, the intensity of the reflected radiation is directly proportional to the relative amount of each species present. Thus one may determine predominant mineralogical influences and provenance. Such information may be significant when swelling clays are involved. Berry and Mason (1959) provided detail concerning x-ray diffraction principles and mineralogical species.

Numerous preparatory treatments were employed in completing x-ray diffraction analyses for the present study. These were incorporated to eliminate the effects of a high carbonate content in the untreated samples. In addition, various temperature and humidity levels were employed to aid in the distinction of specific mineral species. The following preparatory procedures were completed:



$$n\lambda = 2d \sin\Theta$$

n = number of the wave front
λ = wavelength of incoming x-rays
d = interplanar spacing
Θ = angle of incidence/reflection of wave fronts

1. sodium acetate saturation with heating (catalyzes the dissolution of calcium carbonate)
2. Sonication, bleaching, washing (flocculates or disperses the clay-sized fractions (<2μ)), followed by settling to separate the 2 μ fraction. Heating in NH_3 (bleach) removes all organic particles.
3. Individual saturation in Ca,K (enhances the adsorption of Ca, K ions into unoccupied atomic positions within the phyllosilicate framework).
4. Samples are freeze-dried and subhorizontally aligned (permits the preservation of the crystal structure and provides the required enhancement of basal reflections).
5. Selected samples are saturated in ethylene-glycol and tested at various elevated temperatures (these processes enhance reflections and reveal the collapse of crystal structures upon dehydration).

APPENDIX D

APPENDIX D - GEOLOGICAL FIELD TRIP

The author accompanied staff geologists from Gulf Canada Resources Inc. (Calgary) on a 3-day field trip (October 4,5,6, 1982) to explore McMurray and Waterways Formation outcrop throughout the immediate SANDALTA locale. Outcrops were studied at several locations along the MacKay and Muskeg Rivers (Figure D.1) and resulted in the discovery of several structural features.

Location 1 along the MacKay River revealed an undisturbed but well weathered Waterways exposure. Two lithologies were observed correspnding to the marbly (nodular) argillaceous and massive crystalline limestones of rock type A. The exposure displayed well-developed subhorizontal bedding and a highly weathered "nodular" texture with a rubbly talus. In fresh, unweathered core, this lithology displayed a marbly, mottled texture.

Jointing was also observed at Location 1. Two dominant subvertical sets were observed and coincided with those noted by Babcock (1975). Joints were often vertically discontinuous and appeared to be widely developed. Both sets were more well defined in the massive crystalline units than in the nodular lithologies. This was attributed to the reduced thickness and higher stiffness of the massive crystalline unit. No offsets or shear characteristics were observed along joint

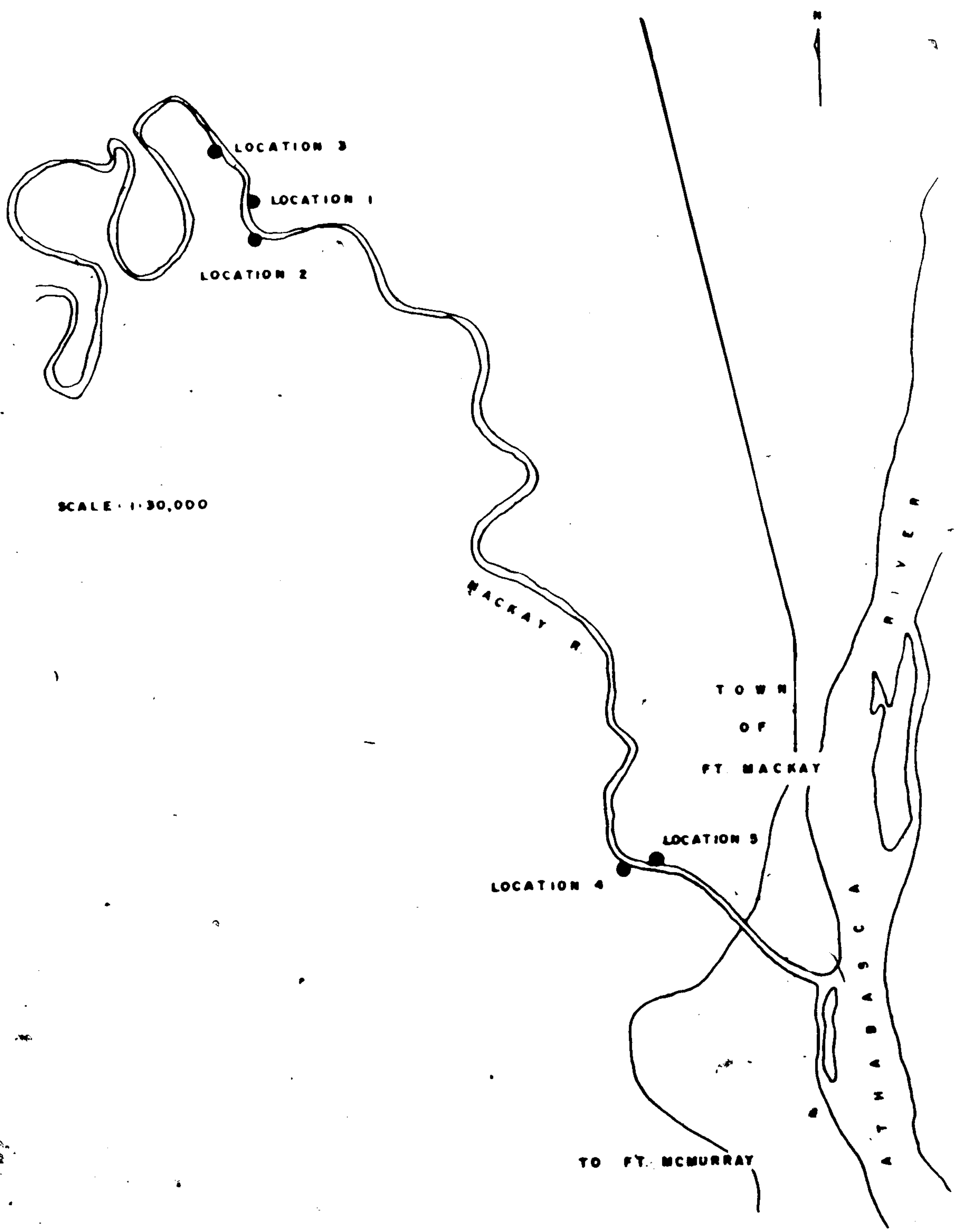


FIGURE D.1: MacKAY RIVER LOCATIONS

faces. Most joint surfaces displayed a moderately weathered tensile character. Bitumen staining was observed throughout the section and had two apparent sources:

1. Devonian organic lenses and bioclastic debris.
2. Post-Devonian fracture infiltration.

Location 2 also displayed nodular lithologies and a sedimentary structure not observed in the study core. Well-defined wave ripple marks were observed on the upper bedding plane of one expos . . The wavelength was 2-4 cm with amplitudes of 1-2 cm. The observed texture was irregular in that a nodular or lumpy appearance dominated the wave pattern. This is thought to be due to the syndepositional development of concretionary carbonate nodules or differential compaction preceding lithification. The irregular ripple pattern may also be partially attributed to irregular or wind-affected wave activity in the shallow marine environment.

In addition to wave ripple marks, a highly fossiliferous limestone unit was observed. Crinoid stems and brachiopod shells dominated the lithology and were easily identified on the exposed outcrop face. Ferrous iron-staining was also observed and a few disseminated bituminous particles were encountered.

Location 3 displayed a subhorizontal sand-filled solution cavity at the base of the western river valley wall. In section, the cavity measured approximately 4 metres long and 0.60 metres thick. It was primarily infilled with clean, medium-grained, bituminous quartz sand, however light green plastic clays were also observed at the base of the cavity. A small (<5 cm) inclined solution pipe was found leading into the cavity and was also infilled with bituminous sand and clay (Figure D.2). The orientation of the cavity appeared to be controlled by the subhorizontal bedding attitude of the host rock, however its three-dimensional character could not be established. Nearby locations on the east river bank also displayed subvertical or inclined narrow solution pipes (<10 cm) infilled with bituminous quartz sands.

Locations 4 and 5 along the MacKay River displayed two additional features of note. Location 4 on the west bank displayed a brittle fracturing phenomenon in beds of nodular to finely interbedded argillaceous limestone. Immediately above the river bed elevation, a distinct break in one of the well-bedded limestone units was accompanied by a mild offset and rotational deformation of the beds on the eastern half of the fracture (Figure D.3). Close examination of the brittle failure surface revealed no shear characteristics such as slickensides,

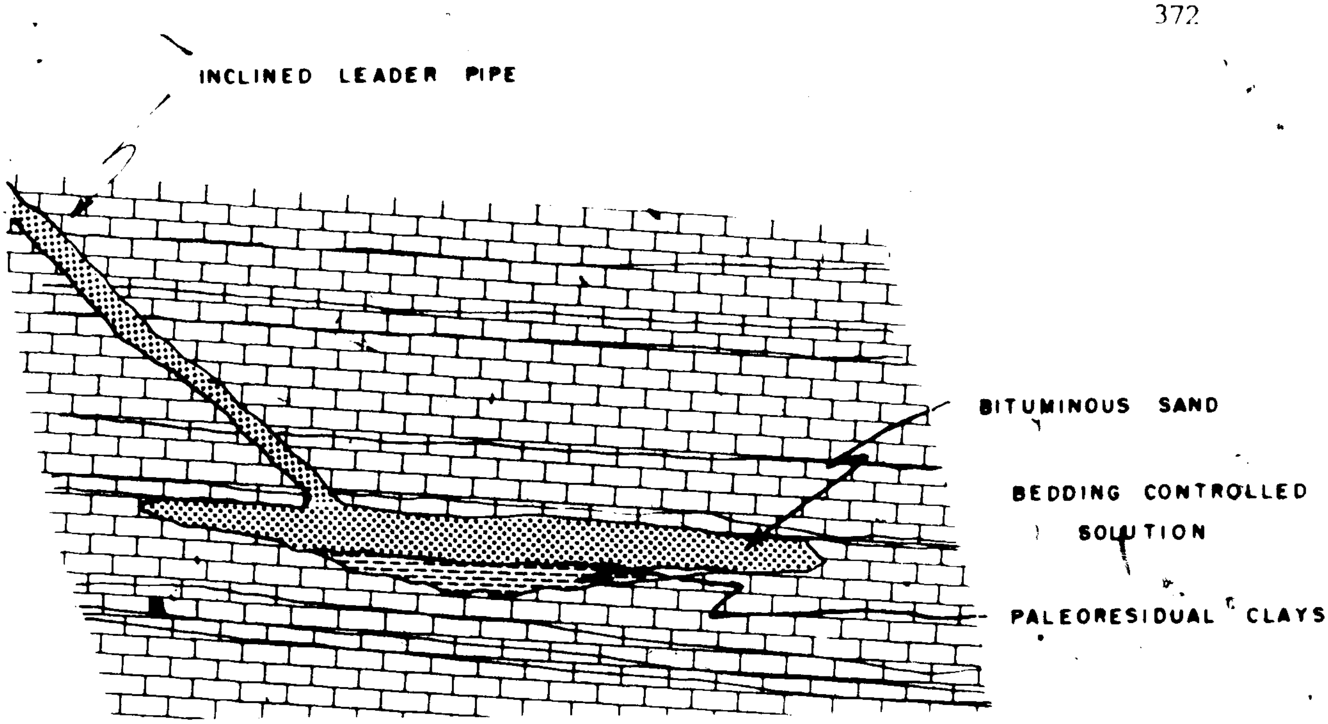


FIGURE D.2: SUBHORIZONTAL SOLUTION CAVITY

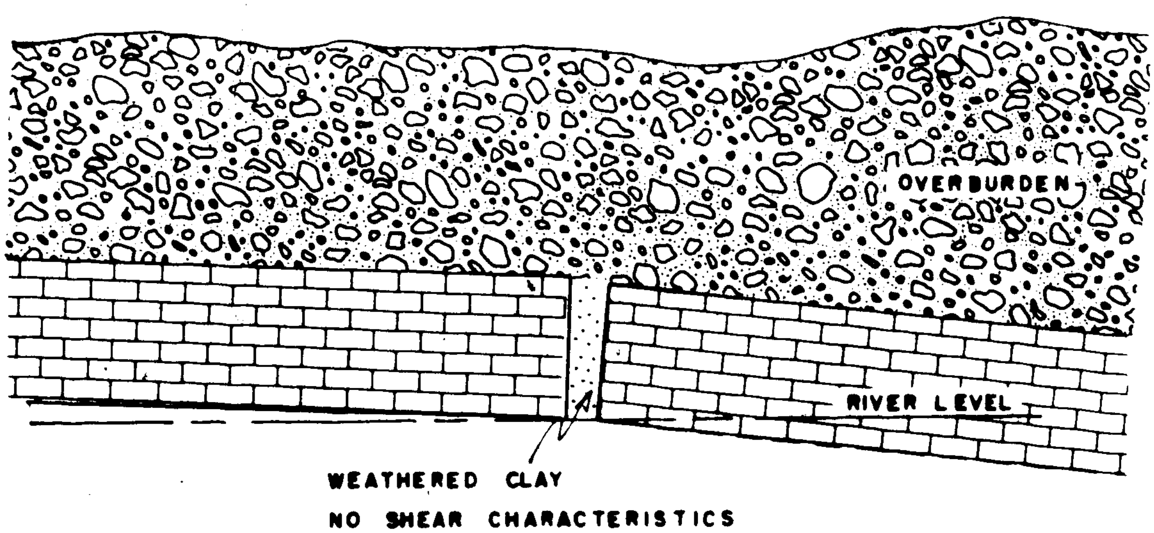


FIGURE D.3: BRITTLE FRACTURE - NO APPARENT SHEAR however the near-vertical discontinuity was infilled with weathered olive clay and silt. This material was not interpreted to represent presheared rock flour or gouge, but rather post-fracture erosional detritus. The non-shear character of the feature was further supported by a lack of measurable vertical offset, however again strike slip shear could not be eliminated.

Location 5 displayed the stratigraphic relationship between the reworked light green paleosols seen throughout the core study and the darker alluvium found infilling various erosional lows in the Paleozoic surface. At site 5 the author observed a w defined weathering profile characterized by gradational changes in the argillaceous limestone upward into the plastic clays that characterize intraformational unconformities. Atop this Paleozoic sequence was a thin (<0.7 m) brown, Cretaceous clay which was in turn overlain by the bituminous sands of the McMurray Formation.

Outcrops visited along the Muskeg River (Figure D.4) also revealed stratigraphic and structural features. One of the most obvious findings was the development of near-vertical river bank cuts in the Waterways members. Again, differential weathering contributed to a very rubbly, nodular texture, however most slopes resided at greater than 80° to the horizontal. A few shallow rotational slides were observed but appeared to initiate in the

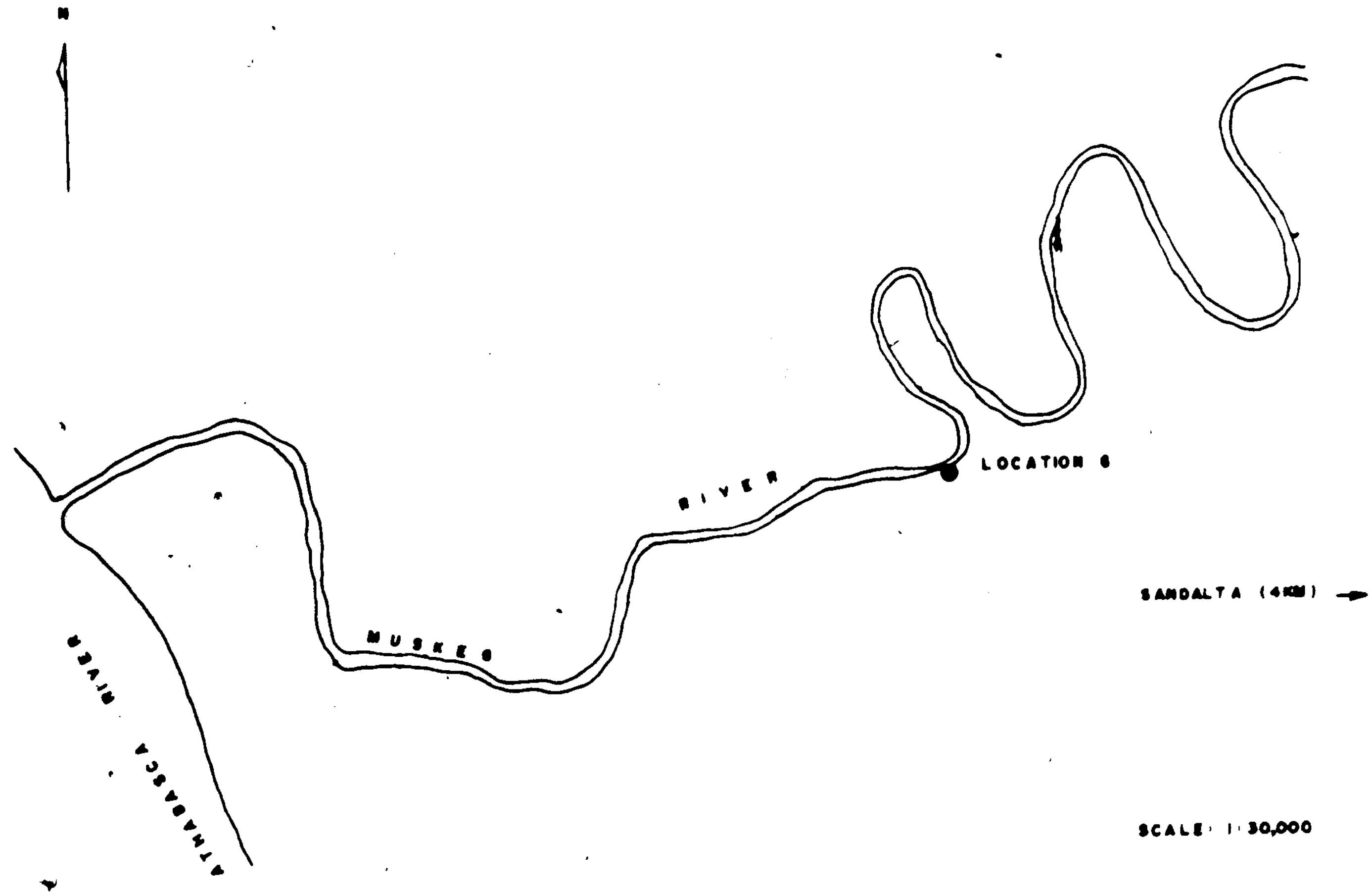


FIGURE D.4: MUSKEG RIVER LOCATIONS

overlying Cretaceous or Tertiary materials. No deep-seated Devonian instability was evident despite 20-30 metre vertical river bank walls.

Brittle fracturing of warped Waterways units was again observed at one Muskeg River outcrop. At Location 6 the author observed what appeared to represent faulting in the formation. More detailed examination revealed that little or no shear offset had occurred and that near-vertical, tensile fracturing of a local subsidence basin was the apparent mechanism.