

**Rigel Oil and Gas Ltd.  
A PETROGRAPHIC  
AND RESERVOIR QUALITY STUDY  
OF TWELVE SAMPLES  
REPRESENTING THE TILSTON BEDS  
IN THE SOUTH PIPESTONE PROVINCE**

**Work Order No. A-7125**

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**EXECUTIVE  
SUMMARY**

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## EXECUTIVE SUMMARY

Thin Section Petrography and Mercury Injection Porosimetry tests were conducted on core samples from the Tilston Beds formation from four wells in the Pipestone area to evaluate reservoir quality and fluid sensitivity issues that effect the producibility of these wells.

Well 15-09-006-26W1M was selected as a very good producer on Rigel's lands. Well 07-16-006-26W1M was selected as an example of a known "economical" horizontal producer on offsetting competitor's lands to the north. Wells 06-09 and 03-09 were the subject wells on Rigel lands that are currently not producing. Samples were selected from each well to represent the best portion of the zone and the poorer portions. Comparisons between wells to evaluate the producing capabilities are primarily based on the samples representing the better reservoir quality.

The petrology identified significant differences in the lithology (grain size, dolomitization and amount of anhydrite, gypsum and calcite cements) across the pool that effect reservoir quality. Similarly, the mercury injection porosimetry showed pore throat size distributions from narrow unimodal systems with large primary pore throat sizes to broad or bimodal systems with small primary pore throats and significant microporosity. It should be noted that the thin section petrology primarily evaluates the pore structure of the reservoir and thus the storage capacity but that the producibility of fluids is more closely related to the pore throat sizes, evaluated by the mercury injection porosimetry.

Both the thin section petrology and the mercury injection porosimetry showed that the reservoir quality of the 15-09 well was significantly better than any of the other wells. Sample 010, representing the top 2 to 3 meters of the zone, was a medium to coarse grained Echinoderm Grainstone with very little cements resulting in 17.6% porosity and excellent permeability (353 md). Mercury Injection porosimetry showed a narrow, unimodal pore throat structure with a peak pore throat radius of about 15 to 20 microns.

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The better portion of the 07-16 well (sample 10) consists of a fine crystalline dolomite with good intercrystalline and microvuggy porosity (25.6%). Despite higher porosity than the 15-09 well, the permeability is significantly lower (42 md) because of the fine grain nature. This is reflected in the porosimetry results, which show a unimodal pore throat structure but with a peak radius of only 2.5 microns.

For the subject wells, the best sample from 06-09 (sample 020) represents a fine crystalline dolomite, similar to the 07-16 well, with 22.2% porosity and 13.5 md gas permeability. The mercury injection shows a slightly broader pore throat size distribution with a peak radius of 1.8 microns. Sample SP002P from 03-09 represents an Echinoderm Grainstone with 12% porosity and 4.07 md permeability. The porosity is controlled by the fine grain nature of the bioclasts and peloids and the amount of cementation. The mercury injection shows a fairly narrow pore throat distribution with a peak radius of 4 microns. These two samples should have only slightly poorer producibility than those from the 07-16 well.

Based on the above analysis and conversations on the drilling and completion techniques employed for the subject horizontal wells, this portion of the reservoir should be capable of producing hydrocarbon fluids but the wellbores were probably damaged in the drilling process. The lithology identified should be fairly acid soluble and therefore should respond to an acid treatment. The fact that the wells would not take any acid would indicate a heavy skin of non-soluble drill solids, probably from uphole shale zones.

These conclusions are based on the assumption that the horizontal wells successfully penetrate the better quality portion of the zones, similar to the core samples analyzed, and that the quality of the reservoir continued areally for some extent along the horizontal section. The extensive variability of the lithology of the samples tested, both vertically and from well to well, combined with the lack of detailed cutting analysis or

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logs along the horizontal wells, would cause some concern about the reliability of this assumption.

## SECTION I



## SECTION SUMMARY

This study describes the petrographic characteristics and reservoir quality of twelve samples, 010 (759.06m), SP002P (760.28m), and SP004P (761.18m) from 15-09-006-26W1M, SP002P (772.18m), SP003P (773.01m), and SP005P (774.59m) from 03-09-006-26W1M, SP002P (773.97m), 020 (776.71m), and SP006P (778.46m) from 06-09-006-26W1M, and #4 (754.70m), #10 (757.60m), and #14 (759.40m) from 07-16-006-26W1M. These samples represent fine to coarse grained bioclastic/echinoderm/peloidal packstones to grainstones. They all have undergone varying degrees of diagenesis which has significantly reduced reservoir quality for most of these rocks. Dolomitization is present in all wells and occurs as either pervasive dolomite of peloidal packstones and grainstones, or as selective dolomitization of bioclastic packstones. Pervasive dolomitization enhances reservoir quality, whereas, selective dolomitization reduces reservoir quality. Gypsum, anhydrite and calcite cements reduces reservoir quality by occluding primary intergranular and moldic porosity. Grain size of the packstone/grainstones is an important factor in determining reservoir quality. Coarse grained grainstones from the 15-09 well represents a good producing well. Whereas, fine grained grainstones to packstones from the 03-09 well is a poor producing well.

Acid sensitivity of the carbonates resulting in possible solution collapse and fines migration, and water blocking due to significant microporosity associated with micrite are problems which can reduce reservoir quality.

## **A PETROGRAPHIC AND RESERVOIR QUALITY STUDY OF THE TILSTON BEDS**

### **INTRODUCTION**

This study describes and compares the mineralogy and reservoir quality for twelve samples from the Tilston Beds representing four wells, 15-09-006-26W1M, 03-09-006-26W1M, 07-16-006-26W1M, and 06-09-006-26W1M. The thin sections were described and photographed to document mineralogy, and reservoir quality controls. Petrography, core analysis and core logging were used to compare the four wells and to determine the differences between a good producing well and a poor producing well.

### **METHOD OF ANALYSIS**

Six samples were selected from the 06-09-006-26W1M and 07-16-006-26W1M wells for thin section preparation and then impregnated with blue epoxy (to reveal porosity), and stained with a combination of Alizarin Red-S (for calcite) and potassium ferricyanide (for ferroan carbonate). Six thin sections from the 15-09-006-26W1M and 03-09-006-26W1M wells already prepared from previous work were also used in this study. These twelve representative samples would be used to illustrate the petrography, and reservoir controls for each of the wells. Tables 1 to 4 summarizes the sample compositions (based on 300 point counts) and textural characteristics. Representative photomicrographs with descriptions of the thin sections are provided at the end of this study (Plates 1-12).

## **PETROGRAPHIC SUMMARY**

The twelve thin sections for this study were selected as representative samples from the four wells in the Rigel South Pipestone province. Samples 010 (759.06m), SP002P (760.28m), and SP004P (761.18m) are from the 15-09-006-26W1M well and represent the good producer. Samples SP002P (772.18m), SP003P(773.10m), SP005P (774.59m) are from the 03-09-006-26W1M well and represent a poor producer. Samples #4 (754.70m), #10 (757.60m), and #14 (759.40m) are from the 07-16-006-26W1M well and represent a moderate producer. Samples SP002P (773.97m), 020 (776.71m), and SP006P (778.46m) are from the 06-09-006-26W1M well. These samples were picked to compare the good producing well with the poor producing well, and their corresponding controls.

### **15-09-006-26W1M**

The 15-09 well represents a good producer in the South Pipestone Province. The three thin sections used for this study were taken near the perforated zone.

Sample 010 (759.06) represents a medium to coarse grained Echinoderm Grainstone (Ech GS) (Plate 1). Compositionally it consists of 99% calcite and 1% dolomite (Table 1), with the dolomite representing very fine to fine crystalline, euhedral rhombs replacing micrite. The fauna is represented mainly by echinoderm fragments (ossicles, plates), with lesser amounts of brachiopods shells, ostracods, gastropods (belemnite), and foraminifera. Other grain types include peloids and micrite. Calcite cement is characterized by syntaxial overgrowths on echinoderm plates, and isopachous rims and sparry calcite on brachiopod, and gastropod shells. The calcite cement constitutes approximately 8% of the calcite population. The non-fauna grain

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types consist of peloids (round micritic masses), and micritic envelopes which coat most of the fauna grains. These micritic coatings may have limited calcite cementation.

Sample SP002P (760.28m) represents a fine grained Echinoderm grainstone (Ech GS) (Plate 2). Compositionally, this sample contains 90% calcite, 3% dolomite, 4% gypsum, and 3% anhydrite (Table 1). The dolomite is very fine to fine crystalline, euhedral rhombs replacing micrite and anhydrite. The anhydrite and gypsum cements occur replacing fauna and/or occluding biomoldic porosity. The fauna is represented mainly by echinoderm fragments (ossicles, plates), with lesser amounts of brachiopods shells, and gastropods (belemnite). Other grain types include peloids and micrite. Calcite cement is characterized by syntaxial overgrowths on echinoderm plates, and isopachous rims and sparry calcite on brachiopod, and gastropod shells. The calcite cement constitutes approximately 15% of the calcite population. Anhydrite cement has a blocky texture, whereas, gypsum has a fibrous texture. The non-fauna grain types consist of peloids (round micritic masses), and micritic patches that infill pore space.

Sample SP004P (761.18m) represents a fine crystalline dolomite, with an original texture of an fine to medium grained Echinoderm packstone (Ech PS) (Plate 3). Compositionally, this sample contains 72% dolomite, 27% gypsum, 1% anhydrite, and trace amounts of bitumen (Table 1). The dolomite is very fine to fine crystalline, euhedral rhombs replacing mainly the micrite. The anhydrite and gypsum occurs replacing fauna or occluding biomoldic porosity. Anhydrite cement has a blocky texture, whereas, the gypsum has a fibrous texture. The fauna is represented mainly by echinoderm fragments (ossicles, plates), and brachiopod shell fragments. Other grain types such as peloids have been dolomitized. Dolomitization is selective in this sample in that the matrix is dolomitized and the bioclastic fragments are unchanged. Calcite cement is characterized by blocky replacement of echinoderm plates.

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### **03-09-006-26W1M**

The 03-09 well is considered to be a poor producer in the South Pipestone province. The three thin sections represent the upper porous zone of the well within the oil zone.

Sample SP002P (772.18m) consists of 83.5% calcite, 13% gypsum, 3.5% anhydrite, and trace amounts of dolomite and pyrite (Table 2). This sample is a limestone and represents a fine grained Echinoderm Grainstone (Ech GS) (Plate 4). The bioclasts are represented by echinoderm (ossicles, plates), brachiopods, ostracods, gastropods (belemnite), coral, and foraminifera. Other grain types include peloids and micrite. Approximately 16% of the calcite volume is represented by calcite cements. Cement types are syntaxial overgrowths on echinoderm fragments, isopachous and sparry overgrowths on brachiopod, gastropod, and coral fragments. Blocky anhydrite and fibrous gypsum cements occur as replacement of skeletal grains, mainly echinoderms. Very fine to fine crystalline, euhedral dolomite crystals occurs replacing micrite matrix and anhydrite.

Sample SP003P (773.01m) consists of 98% calcite, 2% dolomite, and trace amounts of authigenic silica (Table 2). This sample is a limestone and represents a fine grained Echinoderm Grainstone (Ech GS) (Plate 5). The bioclasts are represented by echinoderm (ossicles, plates), brachiopods, ostracods, gastropods (belemnite), mollusk, and foraminifera. Other grain types include peloids and micrite. Approximately 25% of the calcite volume is represented by calcite cements. Cement types are syntaxial overgrowths on echinoderm fragments, isopachous and sparry overgrowths on brachiopod, and gastropods. Dolomite occurs replacing micrite matrix and are very fine to fine crystalline, euhedral crystals.

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Sample SP005P (774.59m) represents a fine crystalline dolomite, with an original texture of an very fine to fine grained Echinoderm packstone (Ech PS) (Plate 6). Compositionally, this samples contains 17% anhydrite, 3% gypsum, 80% dolomite, and trace amounts of authigenic silica (Table 2). The dolomite is very fine to fine crystalline, euhedral rhombs replacing mainly the micritic matrix. The anhydrite and gypsum occurs replacing fauna or occluding biomoldic porosity. Anhydrite cement has a blocky texture, whereas, gypsum has a fibrous texture. The fauna is represented mainly by echinoderm fragments (ossicles, plates). Other grain types include peloids and are completely dolomitized. Dolomitization is selective in this sample in that the matrix is dolomitized and the bioclastic fragments are unchanged.

#### **07-16-006-26W1M**

The 07-16 well represents a moderate producer in the South Pipestone province. The three samples were picked based on lithology, porosity and permeability.

Sample #4 (754.70m) consists of 30% dolomite, 53% calcite, 16% gypsum, and 1% anhydrite (Table 3). This sample is a dolomitic limestone and represents a fine grained Echinoderm Packstone (Ech PS) (Plate 7). The bioclasts are represented by echinoderm fragments (ossicles, plates), brachiopods, gastropod shells (belemnite), and coral. Other grain types include peloids and micrite. Selective dolomitization of the micritic matrix and peloids leaves behind tight patches of dolomite reducing porosity and permeability. Calcite cementation represents 5% of the calcite volume and occurs as syntaxial overgrowths on echinoderm fragments. Blocky anhydrite and fibrous gypsum cements occlude moldic porosity further reducing porosity and permeability.

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Sample #10 (757.60m) represents a fine crystalline dolomite, with an original texture of a very fine to fine grained Peloidal grainstone (Pel GS) (Plate 8). Compositionally, this sample contains 99% dolomite, and 1% authigenic silica (Table 3). The dolomite is fine crystalline, euhedral rhombs replacing the micritic matrix and the peloids leaving behind no original texture. The authigenic silica occurs occluding vuggy porosity. The fauna is represented mainly by echinoderm fragments (ossicles, plates). Other grain types such as peloids are also present. Dolomitization is pervasive in this sample with the matrix and peloids dolomitized.

Sample #14 (759.40m) consists of 3% dolomite, 70% calcite, 14% authigenic silica, 7% anhydrite, and 6% gypsum (Table 3). This sample is a limestone and represents a fine to coarse grained Bioclastic/Peloidal Grainstone (Bio/Pel GS) (Plate 9). The bioclasts are represented by echinoderm fragments (ossicles, plates), gastropod shells (belemnite), and coral. Other grain types include peloids and micrite. Selective dolomitization of the micritic matrix and peloids leaves behind tight patches reducing porosity and permeability. Calcite cementation represents 3% of the calcite volume and occurs as syntaxial overgrowths on echinoderm fragments and isopachous/sparry overgrowths on gastropod shells, and coral internal structure. Blocky anhydrite and fibrous gypsum cements occlude moldic porosity further reducing porosity and permeability.

#### **06-09-006-26W1M**

The 06-09 well is similar to the 03-09 well. The thin sections were selected with one above the porous zone, one in the porous zone, and one below the porous zone.

Sample SP002P (773.97m) represents a fine crystalline dolomite, with an original texture of a very fine to coarse grained Echinoderm packstone (Ech PS) (Plate 10). Compositionally, this

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samples contains 25% anhydrite, and 75% dolomite (Table 4). The dolomite is very fine to fine crystalline, euhedral rhombs replacing mainly the micritic matrix. The anhydrite occurs replacing fauna or occluding biomoldic porosity. Anhydrite cement has a blocky texture. The fauna is represented mainly by echinoderm fragments (ossicles, plates), brachiopods, and gastropod fragments. Other grain types such as peloids are also present. Dolomitization is selective in this sample replacing the matrix and leaving the bioclastic fragments unchanged.

Sample 020 (776.71m) represents a fine crystalline dolomite, with an original texture of very fine to medium grained Echinoderm Wackestone (Ech WS) (Plate 11). Compositionally, this sample contains, 88% dolomite, 12% gypsum, and trace amounts of anhydrite (Table 4). The dolomite is fine crystalline, euhedral rhombs replacing the micritic matrix and the peloids leaving behind no original texture. The anhydrite and gypsum occurs replacing occluding vuggy porosity. Anhydrite cement has a blocky texture and the gypsum has a fibrous texture. The fauna is represented mainly by echinoderm fragments (ossicles, plates). Other grain types such as peloids are also present. Dolomitization is pervasive in this sample replacing the matrix and peloids.

Sample SP006P (778.46m) consists of 64% calcite, 15% dolomite, 19% gypsum, and 2% anhydrite (Table 4). This sample is a limestone and represents a fine to medium grained Echinoderm Packstone (Ech PS) (Plate 12). The bioclasts are represented by echinoderm (ossicles, plates), brachiopods, gastropods (belemnite), and coral. Other grain types include peloids and micrite. Approximately 8% of the calcite volume is represented by calcite cements. Cement types are syntaxial overgrowths on echinoderm fragments, isopachous and sparry overgrowths on brachiopod, and gastropods. Dolomite occurs replacing micrite matrix and are very fine to fine crystalline, euhedral crystals. Anhydrite occurs as a blocky cement and gypsum has a fibrous texture, both of which occlude biomoldic porosity.

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## LITHOLOGY

The lithology for the Tilston Beds is based on the textural differences observed during the core examination of 4 wells supplied for this study.

The Tilston Beds are located in Southwest Manitoba, to Southeast Saskatchewan, and down to north-central North Dakota. It has been subdivided into two intervals. The lower interval consists of oolitic-pisolitic and crinoidal grainstones and packstones, whereas, the upper unit consists of argillaceous, silty limestone or dolomitic limestone with shale partings (Glass, 1990).

The Tilston Beds located within the Pipestone Province consist of fine to coarse grained crinoidal grainstones to packstones, with occasional fine grained crinoidal wackestones and mudstones. Some of the crinoidal packstones and wackestones have been selectively dolomitized leaving behind interbedded dolomite beds among the limestone beds. Both dolomite and limestone beds contain significant amounts of anhydrite and gypsum which increases toward the top of the formation. The grainstones and packstones consist of mainly echinoderm fragments (ossicles and plates), with lesser amounts of brachiopod shells, gastropod fragments (belemnite), coral, foraminifera, and ostracods. Other grain types are peloids, which are spherical micritic masses and can either represent fecal pellets or extensively micritized skeletal grains, and micritic envelopes and micrite. The presence of micritic envelopes indicate that these lithofacies must have been in the photic zone (<100-200m). Micrite deposition usually occurs in depositional environments such as tidal flats and shallow lagoons to deep-sea floor. Micrite can also occur on slopes. The presence of echinoderm grainstones and packstones suggests that the main depositional environment is subtidal shoals along shelf margins. Some of the wells show a overall coarsening upwards sequence from fine grained grainstones and packstones to coarse

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grained grainstones. This suggests that the sand shoals may be prograding into a lagoonal environment (Tucker, 1991).

## **POROSITY AND PERMEABILITY**

The twelve samples represent echinoderm and peloidal grainstones and packstones which occur as interbedded limestone and dolomite beds. The main factors controlling reservoir quality for this formation are depositional textures, and diagenesis. Primary intergranular porosity for the limestones is modified by the precipitation of diagenetic minerals such as calcite cement, anhydrite, gypsum, and authigenic silica. Secondary intercrystalline, dissolution porosity (biomoldic), and microvug porosity can be modified by the precipitation of calcite, gypsum, and anhydrite cement. Microporosity (associated predominantly with micrite) can be a common pore type, especially in limestone (packstone) samples. A Mercury Injection Porosimetry study was done on representative samples from the four wells to better understand the pore system. The Mercury Injection Porosimetry Study is added to the back of this report in Section III. The core logs for the four wells are in Section II.

### **15-09-006-26W1M**

Sample 010 (759.06m), represents a coarse grained Echinoderm Grainstone, and is considered to have good reservoir quality. Core analysis porosity is 17.6%, thin section porosity is 12%, and measured permeability of 353md. The good porosity values and high permeability can be attributed to the coarse grained particles, low percent of micrite and calcite cement, and no anhydrite cement. Mercury injection porosimetry tests for this sample indicate that the pore system is unimodal indicating the dominant pore throat radius is between 15-20 microns (Figures # 13 & 14, Section III) indicating good intergranular porosity.

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Sample SP002P (760.28m), represents a fine grained Echinoderm Grainstone, and is considered to have moderate reservoir quality. Core analysis porosity is 17.5%, thin section porosity of 8%, and measured permeability of 10.3md. The discrepancy in porosities can be attributed to the presence of secondary moldic porosity associated with the fauna and microporosity associated with micrite. The good porosity values and moderate permeability can be attributed to the fine grain size and the presence of calcite, gypsum, and anhydrite cement. Mercury injection porosimetry tests were not done on this sample

Sample SP004P (761.18m), represents a fine crystalline dolomite with an original texture of Echinoderm Packstone. It is considered to have moderately poor reservoir quality. This sample has core analysis porosity of 14.5%, thin section porosity of 1%, and measured permeability of 1.04md. The discrepancy in porosities can be attributed to the presence of microintercrystalline porosity associated with the dolomite. The moderate porosity value and moderately poor permeability can be attributed to dolomitization, gypsum and anhydrite cements. Mercury injection porosimetry tests on this sample indicate that the pore system has a broad range for the pore throat radius. The pore throat radius has a range from 0.15 to 0.9 microns (Figures #15 & 16, Section III), indicating microintercrystalline and biomoldic porosity.

### **03-09-006-26W1M**

Sample SP002P (772.18m), represents a fine grained Echinoderm Grainstone, and is considered to have moderate reservoir quality. This sample has core analysis porosity of 12%, thin section porosity is 8%, and measured permeability of 4.07md. The moderate porosity values and permeability can be attributed to the fine grained particles, and significant amount of gypsum and anhydrite cement. Mercury injection porosimetry tests for this sample indicates that the pore

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system is unimodal, with the pore throat radius being 4 microns (Figures #5 & 6, Section III) indicating moderate intergranular porosity.

Sample SP003P (773.01m), represents a fine grained Echinoderm Grainstone, and is considered to have moderately poor reservoir quality. This sample has core analysis porosity of 11.7%, thin section porosity of 9%, and measured permeability of 1.52md. The discrepancy in porosities can be attributed to the presence of secondary moldic porosity associated with the fauna and microporosity associated with micrite. The moderate porosity values and moderate poor permeability can be attributed to the fine grain size and the presence of calcite and anhydrite cement. Mercury injection porosimetry tests was not done on this sample.

Sample SP005P (774.59m), represents a fine crystalline dolomite with an original texture of Echinoderm Packstone. It is considered to be of poor reservoir quality. This sample has core analysis porosity of 10.7%, thin section porosity of 5%, and measured permeability of 0.37md. The discrepancy in porosities can be attributed to the presence of microintercrystalline porosity associated with the dolomite. The moderate porosity value and poor permeability can be attributed to dolomitization, gypsum and anhydrite cementation. Mercury injection porosimetry tests for this sample indicate that the pore system is trimodal where the 0.15 micron pore throat radius represents the microintercrystalline porosity, the 0.33 micron pore throat radius represents intercrystalline porosity, and the 0.8 micron pore throat radius represents the biomoldic porosity (Figures #7 & 8, Section III).

#### **07-16-006-26W1M**

Sample #4 (754.70m), represents a dolomitic limestone, representing a fine grained Echinoderm Packstone, and is considered to have moderately poor reservoir quality. This sample has core

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analysis porosity is 14.1%, thin section porosity is 13.5%, and measured permeability of 1.7md. The moderate porosity values and moderately poor permeability can be attributed to partial dolomitization, calcite cement, gypsum and anhydrite cement. Mercury injection porosimetry tests on this sample indicate that the pore system is slightly bimodal suggesting that there is both intergranular and microporosity pore types are present. The 1.1 micron pore throat radius represents the intergranular and moldic porosity, whereas, the 0.05 micron pore throat radius represents microporosity associated with the micrite (Figures #9 & 10, Section III).

Sample #10 (757.60m), represents a fine crystalline dolomite, with an original texture of a very fine to fine grained Peloidal Grainstone, and is considered to have good reservoir quality. This sample has core analysis porosity is 25.6%, thin section porosity of 24%, and measured permeability of 47md. The good porosity and permeability values can be attributed to good intercrystalline porosity and no calcite and anhydrite cements. Mercury injection porosimetry tests indicate that the pore system is unimodal with mainly intercrystalline porosity at a pore throat radius of 2.5 microns (Figures #11 & 12, Section III).

Sample #14 (759.40m), represents a fine to coarse grained Bioclastic/Peloidal Grainstone. It is considered to have moderate reservoir quality. This sample has core analysis porosity of 16.9%, thin section porosity of 10%, and measured permeability of 15md. The discrepancy in porosities can be attributed to the presence of microporosity associated with the micrite, and secondary moldic porosity of fauna. The moderate porosity and permeability values can be attributed to the presence of gypsum, anhydrite, calcite cements, and authigenic silica. Mercury injection porosimetry tests were not performed on this sample.

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## 06-09-006-26W1M

Sample SP002P (773.97m), represents a fine crystalline dolomite, with an original texture of a very fine to coarse grained Echinoderm Packstone, and is considered to have poor reservoir quality. This sample has core analysis porosity of 13.2%, thin section porosity is 12%, and measured permeability of 0.91md. The moderate porosity values and low permeability can be attributed to dolomitization and anhydrite cement. Mercury injection porosimetry tests for this sample indicate that the pore system is bimodal suggesting that there is both biomoldic and intercrystalline pore types present. The pore throat radius at 0.2 microns represents the intercrystalline porosity, and the pore throat radius at 1.3 microns represents the biomoldic porosity (Figures #1 & 2, Section III).

Sample 020 (776.71m), represents a fine crystalline dolomite, with an original texture of an very fine to medium grained Echinoderm Wackestone, and is considered to be of moderate reservoir quality. This sample has core analysis porosity of 22.2%, thin section porosity of 18%, and measured permeability of 13.5md. The discrepancy in porosities can be attributed to the presence of microintercrystalline porosity associated with dolomitization. The good porosity values and moderate permeability can be attributed to the fine crystalline euhedral dolomite which has pervasively replaced the matrix, and the presence of gypsum and anhydrite cements. Mercury injection porosimetry tests indicate that the pore system is slightly bimodal with the pore throat radius of 0.4 microns representing the intercrystalline porosity, and the pore throat radius of 1.8 microns representing the moldic or microvuggy porosity (Figures #3 & 4, Section III).

Sample SP006P (778.46m), represents a fine to medium grained dolomitic limestone representing a Echinoderm Packstone. It is considered to have poor reservoir quality. This

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sample has core analysis porosity of 11.6%, thin section porosity of 8%, and measured permeability of 0.32md. The discrepancy in porosities can be attributed to the presence of microintercrystalline porosity associated with the dolomite, and moldic porosity from fauna. The moderate porosity value and poor permeability can be attributed to dolomitization, gypsum and anhydrite cementation. Mercury injection porosimetry tests were not done on this sample.

## **RESERVOIR QUALITY**

Samples 010 (759.06m), SP002P (760.28m), and SP004P (761.18m), from the 15-09-006-26W1M well, has poor to good reservoir quality. Samples SP002P (772.18m), SP003P (773.01m), and SP005P (774.59m), from the 03-09-006-26W1M well, has poor to moderate reservoir quality. Samples #4 (754.70m), #10 (757.60m), and #14 (759.40m), from the 07-16-006-26W1M well, has poor to good reservoir quality. Samples SP002P (773.97m), 020 (776.71m), and SP006P (778.46m), from the 06-09-006-26W1M well, has poor to moderate reservoir quality. Depositional environment (grain size and amount of micrite) and diagenesis (calcite, gypsum and anhydrite cements, dolomitization) appears to be the main factors controlling reservoir quality. Acid sensitivity will be the main problem to the reduction in reservoir quality. Acidization could cause dissolution of the limestone and dolomite which can result in solution collapse in the limestone and fines migration of the very fine to fine crystalline dolomite rhombs. Scale formation can be a problem because of the significant amounts of gypsum and anhydrite present if there is a change in the physical conditions during production. There is several methods which can be used to remove this scale. An EDTA solution can be used to form a soluble complex. A inorganic converter (ammonium carbonate) will convert the calcium sulphate to acid soluble calcium carbonate, and organic converters (sodium citrate, potassium glycolate, and potassium acetate) will calcium sulphate to become soft and be easily removed by water flushing.

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Samples with micrite will have significant amounts of microporosity. These samples usually have low permeability values (ie. wackestone, packstone). Therefore, water block could be a problem in low permeable, microporous carbonates. The use of surfactants can be used to reduce the interfacial tension between the fluids and allowing it to flow.

## **PRODUCTION VS. LITHOLOGY**

Production from the Tilston Beds at the South Pipestone Province comes from carbonates. However, the type of carbonate (dolomite, and limestone), amount of diagenesis (percent of cements), and primary grain size makes a significant difference on the performance of each of the wells.

The 15-09 well represents the best producer of the four wells examined. There are several factors that contribute to this good production. The top two to three meters below the anhydritic zone consists of medium to coarse grained Echinoderm Grainstones with no to very little anhydrite cement and minor amounts of calcite cement occluding pore space. This grades down into a fine grained Echinoderm Grainstone with gypsum and anhydrite cements and a greater amount of calcite cement occluding pore space. The presence of these cements combined with the decrease in grain size contribute to the reduction in reservoir quality. Sample 010 (759.06m), represents a medium to coarse grained Echinoderm Grainstone and has a core analysis porosity of 17.6, and measured permeability of 353md. The coarse grained bioclasts combined with the lack of cement allow for good interconnectivity giving the high permeability values. Sample SP002P (760.28m), has core analysis porosity of 17.5%, and measured permeability of 10.3md. Porosity is similar to sample 010, but the permeability is considerably less than sample 010. This decrease can be attributed to the finer grained size, decreasing pore throat size, and the

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increase in pore occluding cements (anhydrite, gypsum, and calcite). Sample SP004P (761.18m) represents a fine crystalline dolomite. Core analysis porosity is 14.5%, and measured permeability is 1.04md. This reduction in porosity and permeability is attributed to selective dolomitization of the Echinoderm Packstone micritic matrix. The bioclastic fragments have been untouched by dolomitization and have not been dissolved to produce secondary moldic porosity. The bioclasts have been replaced by gypsum and anhydrite. Core observation indicates that the top two meters is anhydrite and dolomite, with the majority of the core ranging from coarse to fine grained echinoderm grainstones with a one meter section that has been completely dolomitized. This homogeneity may contribute to the overall improvement in the reservoir quality with the reduction in low permeability barriers.

The 03-09 well represents a poor producer in the Rigel South Pipestone Province. The factors controlling reservoir quality are the fine grain size of the bioclasts, the amount of cementation (calcite, gypsum, anhydrite), and dolomitization. Sample SP002P (772.18m) represents a Echinoderm Grainstone. Core analysis porosity is 12%, and measured permeability is 4.07md. This moderate porosity and permeability sample is controlled by the fine grain size of the bioclasts and peloids, and the amount of cementation occluding pore space (calcite, gypsum, anhydrite). Sample SP003P (773.01m) represents a Echinoderm Grainstone. Core analysis porosity is 11.7%, and measured permeability is 1.57md. The reservoir quality of this sample is controlled by the fine grain size and the amount of cementation (calcite). Sample SP005P (774.59m) represents a fine crystalline dolomite. Core analysis porosity is 10.7md, and measured permeability is 0.37md. The poor reservoir quality represented by this sample can be attributed to the original texture (bioclastic packstone) and selective dolomitization of the micritic matrix. Anhydrite and gypsum has replaced the calcite of the bioclasts. Core observation of the 03-09 well indicates a interbedded low permeable dolomite with moderate

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permeable limestones (echinoderm grainstones to packstones). This suggests poor interconnectivity for this reservoir.

The 07-16 well represents a moderate producing well. The factors controlling the moderately poor to good quality reservoir for this well are diagenesis (dolomitization, gypsum, anhydrite), and grain size. Sample #4 (754.70m) represents a dolomitic limestone, with an original texture of a Echinoderm Packstone. Core analysis porosity is 14.1%, and measured permeability is 1.7md. The moderately poor permeability is attributed to significant amounts of anhydrite, gypsum, and calcite cements, selective dolomitization of the micritic matrix, and fine grained bioclasts. Sample #10 (757.60m) represents a fine crystalline dolomite, with a original texture of a peloidal grainstone. This allowed for good intercrystalline and microvuggy porosity (core analysis porosity of 25.6%), and good permeability (47md). Sample #14 (759.40m) represents a Bioclastic/Peloidal Grainstone. Moderate core analysis porosity (16.9%), and moderate measured permeability (15md) can be attributed to moderate amounts of gypsum, anhydrite, and calcite cements, and authigenic silica occluding moldic porosity in coarse grained bioclasts. Overall core observation suggests moderately poor permeable limestones throughout the core with a one meter of moderately good to good permeable dolomite in the upper section of the core. The moderate production is the result of moderately poor permeability limestone present throughout the core with a thin moderate permeability dolomite layer in the upper portion of the core.

The 06-09 well is non-producing well. The factors controlling the reservoir quality in this sample is diagenesis (anhydrite, and gypsum cements, dolomitization), and original texture. Sample SP002P (773.97m) represents a fine crystalline dolomite, with an original texture of an Echinoderm Packstone. Core analysis porosity of 13.2%, and measured permeability of 0.91md which is suggestive of poor reservoir quality. Selective dolomitization of the micritic matrix,

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and anhydritization of the bioclasts significantly reduces the permeability of the sample. Sample 020 (776.71m) represents a fine crystalline dolomite, with an original texture of an Echinoderm Wackestone. Core analysis porosity is 22.2%, and measured permeability is 13.5md. This moderate reservoir quality sample is controlled by the original texture, and diagenesis. The original echinoderm wackestone texture allowed for pervasive dolomitization of the lithology allowing for good intercrystalline porosity to developed. The lack of calcitic bioclasts decreased the ability for anhydrite to precipitate. Sample SP006P (778.46m) represents a dolomitic limestone (Echinoderm Packstone). Selective dolomitization of the micritic matrix and anhydrite and gypsum replacement of the calcitic bioclasts attribute to the poor measured permeability of 0.32md, and core analysis porosity of 11.6%. The rest of the core indicates very fine to fine grained limestone (crinoidal wackestone to grainstone) with moderate reservoir quality. This area however, lies below the oil-water contact. The core within the oil zone is represented by interbedded low permeable, low to moderate porosity limestones and dolomites.

In conclusion, the best reservoir quality rock types identified in the Tilston Beds, Rigel South Pipestone Province can be either limestones or dolomites depending upon the original texture. For the limestones, the best quality reservoirs will be from medium to coarse grained, relatively cement free (gypsum, anhydrite and calcite), echinoderm grainstones. These rock types have good porosity and permeability values due to large unoccluded pore space with large pore throat sizes allowing for good interconnectivity. The poorer quality limestone reservoirs are characterized by bioclastic packstones to wackestones containing micrite. These rock types have undergone more extensive diagenesis resulting in the precipitating of pore space occluding anhydrite and calcite cements. Selective dolomitization of the micrite matrix reduces porosity and permeability, thus reducing interconnectivity of the pore space. Good dolomite beds have original textures of peloidal packstones to grainstones. The lack of bioclasts allow for pervasive dolomitization of the micritic matrix and pellets producing good intercrystalline porosity.

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Dolomitization reduces reservoir quality in beds that represent bioclastic and echinoderm packstones. Selective dolomitization of the micritic matrix leaving behind the bioclasts which have been replaced by gypsum and anhydrite. Anhydrite and gypsum also occlude any vuggy porosity present. Selective dolomitization only produces poor to moderate intercrystalline porosity and poor permeability which may be due to the presence of the bioclasts.

## REFERENCES

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## TABLES & FIGURES

**Table 1**  
**Petrographic Summary of Samples from the**  
**Tilston Fm. at 15-09-006-26W1M**

	<b>010</b> <b>759.06m</b>	<b>SP002P</b> <b>760.28m</b>	<b>SP004P</b> <b>761.18m</b>
<b>FRAMEWORK GRAINS</b>			
<i>Dolomite</i>	1	3	72
<i>Calcite</i>	99	90	-
<i>Anhydrite</i>	-	3	1
<i>Gypsum</i>	-	4	27
<i>Authigenic Silica</i>	-	-	-
<i>Pyrite</i>	-	-	-
<i>Phosphate</i>	-	-	-
<i>Bitumen</i>	-	-	TR
<b>FAUNA</b>	Ech, Bra, Os Foram, Gas	Ech, Gas, Bra	Ech, Bra
<b>GRAIN TYPES</b>	Peloids, micrite	Peloids, micrite	-
<b>CRYSTAL TEXTURE (DOL)</b>	Euh	Euh	Euh
<b>GRAIN SIZE (DOL)</b>	Fxl	VFxl-Fxl	Vfxl-Fxl
<b>CEMENT TYPES</b>			
<i>Calcite</i>	Syn, Iso	Syn, Iso	Blo
<i>Anhydrite</i>	-	Blo	Blo
<i>Gypsum</i>	-	Fib	Fib
<b>CALCITE CEMENT (%)</b>	8	15	-
<b>ROCK TYPE</b>	LS	LS	Fxl Dolomite
<b>ORIGINAL TEXTURE</b>	Ech GS	Ech Gs	Ech PS
<b>GRAIN SIZE (LS)</b>	Mg-Cg	Fg	Fg-Mg
<b>POROSITY TYPES</b>	Ig, Mo	Ig, Mo	Ixl
<b>CORE POROSITY (%)</b>	17.6	17.5	14.5
<b>TS POROSITY (%)</b>	12	8	1
<b>PERMEABILITY (md)</b>	353	10.3	1.04
<b>QUALITY</b>	G	M	MP

**Table 2**  
**Petrographic Summary of Samples from the**  
**Tilston Fm. at 03-09-006-26W1M**

	<b>SP002P</b> <b>772.18m</b>	<b>SP003P</b> <b>773.01m</b>	<b>SP005P</b> <b>774.59m</b>
<b>FRAMEWORK GRAINS</b>			
<i>Dolomite</i>	TR	2	80
<i>Calcite</i>	83.5	98	-
<i>Anhydrite</i>	3.5	-	17
<i>Gypsum</i>	13	-	3
<i>Authigenic Silica</i>	-	TR	TR
<i>Pyrite</i>	TR	-	-
<i>Phosphate</i>	-	-	-
<i>Bitumen</i>	-	-	-
<b>FAUNA</b>	Ech, Bra, Os Foram, Gas, Cor, Foram	Ech, Gas, Bra, Moll, Foram, Os	Ech
<b>GRAIN TYPES</b>	Peloids, micrite	Peloids, micrite	Peloids
<b>CRYSTAL TEXTURE (DOL)</b>	Euh	Euh	Sub-Euh
<b>GRAIN SIZE (DOL)</b>	Fxl	Fxl	VFxl-Fxl
<b>CEMENT TYPES</b>			
<i>Calcite</i>	Syn, Iso	Syn, Iso, Blo	-
<i>Anhydrite</i>	Blo	-	Blo
<i>Gypsum</i>	Fib	-	Fib
<b>CALCITE CEMENT (%)</b>	16	25	-
<b>ROCK TYPE</b>	LS	LS	Fxl Dolomite
<b>ORIGINAL TEXTURE</b>	Ech GS	Ech GS	Ech PS
<b>GRAIN SIZE (LS)</b>	Vfg-Fg	Fg	VFg-Cg
<b>POROSITY TYPES</b>	Ig, Mo, mV	Ig, Mo	Ixl, Mo, mV
<b>CORE POROSITY (%)</b>	12	11.7	10.7
<b>TS POROSITY (%)</b>	8	9	5
<b>PERMEABILITY (md)</b>	4.07	1.52	0.37
<b>QUALITY</b>	M	MP	P

**Table 3**  
**Petrographic Summary of Samples from the**  
**Tilston Fm. at 06-09-006-26W1M**

	<b>SP002P</b> <b>773.97m</b>	<b>020</b> <b>776.71m</b>	<b>SP006P</b> <b>778.46m</b>
<b>FRAMEWORK GRAINS</b>			
<i>Dolomite</i>	75	88	15
<i>Calcite</i>	-	-	64
<i>Anhydrite</i>	25	TR	2
<i>Gypsum</i>	-	12	19
<i>Authigenic Silica</i>	-	-	-
<i>Pyrite</i>	-	-	-
<i>Phosphate</i>	-	-	-
<i>Bitumen</i>	-	-	-
<b>FAUNA</b>	Ech, Bra, Gas	Ech	Ech, Gas, Bra, Cor
<b>GRAIN TYPES</b>	Pel	Pel	Pel, Micrite
<b>CRYSTAL TEXTURE (DOL)</b>	Sub-Euh	Sub-Euh	Sub-Euh
<b>GRAIN SIZE (DOL)</b>	Fxl	Fxl	Fxl
<b>CEMENT TYPES</b>			
<i>Calcite</i>	-	-	Syn, Iso
<i>Anhydrite</i>	Blo	Blo	Blo
<i>Gypsum</i>		Fib	Fib
<b>CALCITE CEMENT (%)</b>	-	-	8
<b>ROCK TYPE</b>	Fxl Dolomite	Fxl Dolomite	Dol LS
<b>ORIGINAL TEXTURE</b>	Ech PS	Ech WS	Ech PS
<b>GRAIN SIZE (LS)</b>	VFg-Cg	VFg-Mg	Fg-Mg
<b>POROSITY TYPES</b>	lxl, Mo	lxl	lg, Mo
<b>CORE POROSITY (%)</b>	13.2	22.2	11.6
<b>TS POROSITY (%)</b>	12	18	8
<b>PERMEABILITY (md)</b>	0.91	13.5	0.32
<b>QUALITY</b>	P	M	P

**Table 4**  
**Petrographic Summary of Samples from the**  
**Tilston Fm. at 07-16-006-26W1M**

	<b>4</b> <b>754.70m</b>	<b>10</b> <b>757.60m</b>	<b>14</b> <b>759.40m</b>
<b>FRAMEWORK GRAINS</b>			
<i>Dolomite</i>	30	99	3
<i>Calcite</i>	53	-	70
<i>Anhydrite</i>	1	-	7
<i>Gypsum</i>	16	-	6
<i>Authigenic Silica</i>	-	1	14
<i>Pyrite</i>	-	-	-
<i>Phosphate</i>	-	-	-
<i>Bitumen</i>	-	-	-
<b>FAUNA</b>	Ech, Bra Gas, Cor	Ech	Ech, Gas, Cor
<b>GRAIN TYPES</b>	Pel, micrite	Pel	Pel, Micrite
<b>CRYSTAL TEXTURE (DOL)</b>	Sub-Euh	Sub-Euh	Sub-Euh
<b>GRAIN SIZE (DOL)</b>	VFxl-Fxl	VFxl-Fxl	Fxl
<b>CEMENT TYPES</b>			
<i>Calcite</i>	Syn	-	Syn, Iso
<i>Anhydrite</i>	Blo	-	Blo
<i>Gypsum</i>	Fib	-	Fib
<b>CALCITE CEMENT (%)</b>	5	-	3
<b>ROCK TYPE</b>	Dol LS	Fxl Dolomite	LS
<b>ORIGINAL TEXTURE</b>	Ech PS	Pel GS	Bio/Pel GS
<b>GRAIN SIZE (LS)</b>	Fg-Cg	-	Cg
<b>POROSITY TYPES</b>	lxl, Mo, lg	lxl, mV	Mo, lg
<b>CORE POROSITY (%)</b>	14.1	25.6	16.9
<b>TS POROSITY (%)</b>	13.5	24	10
<b>PERMEABILITY (md)</b>	1.7	47	15
<b>QUALITY</b>	MP	G	M

## **LIST OF ABBREVIATIONS**

### **FAUNA**

Bry	-	BRYOZOAN
Ech	-	ECHINODERM
Bra	-	BRACHIOPOD
Os	-	OSTRACOD
Cal	-	CALCISPHERES
Biv	-	BIVALVE
Moll	-	MOLLUSK
Foram	-	FORAMINIFERA
Strom	-	STROMATOPOROID
Cor	-	CORAL
Ga	-	GASTROPOD
Pele	-	PELECYPOD

### **CRYSTAL TEXTURE**

Euh	-	EUHEDRAL
Sub	-	SUBHEDRAL
Anh	-	ANHEDRAL

### **ORIGINAL TEXTURE**

DOLOGS	-	DOLOGRAINSTONE
DOLOPS	-	DOLOPACKSTONE
DOLOWS	-	DOLOWACKESTONE
DOLOMS	-	DOLOMUDSTONE
DOLOFS	-	DOLOFLOATSTONE
DOLORS	-	DOLORUDSTONE

### **GRAIN TYPES**

Pel	-	PELOID
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### **GRAIN SIZE**

Cxl	-	COARSE CRYSTALLINE
Mxl	-	MEDIUM CRYSTALLINE
Fxl	-	FINE CRYSTALLINE
Vfxl	-	VERY FINE CRYSTALLINE

### **POROSITY TYPES**

Mixl	-	MICROINTERCRYSTALLINE
Ixl	-	INTERCRYSTALLINE
Mo	-	BIOMOLDIC
mV	-	MICROVUGGY
mF	-	MICROFRACTURE
Ig	-	INTERGRANULAR

### **QUALITY**

G	-	GOOD
M	-	MODERATE
P	-	POOR

### **CEMENT TYPES**

Syn	-	SYNTAXIAL OVERGROWTHS
Blo	-	BLOCKY
Poik	-	POIKILOTOPIC
Dru	-	DRUSY
SD	-	SADDLE DOLOMITE
Lath	-	ANHYDRITE LATHS
Grm	-	GROUNDMASS
Iso	-	ISOPACHOUS RIMS

**APPENDICES**

**APPENDIX I**

**THIN SECTION PHOTOMICROGRAPHS AND DESCRIPTIONS**

THIN SECTION DESCRIPTION: PLATE 1

WELL: 15-09-006-26W1M

TILSTON BEDS

ECHINODERM GRAINSTONE

Porosity: 17.6%

Permeability: 353md

SAMPLE 010, 759.06m

- 1 Overview of a medium to coarse grained Echinoderm Grainstone. This limestone consists mainly of calcite, with minor amounts of dolomite. The bioclasts are represented by echinoderm fragments (ossicles, plates), brachiopods, ostracods, foraminifera, and gastropods (belemnite). Other grain types include peloids and micritic envelopes. Primary intergranular porosity has been reduced by minor amounts of calcite cement (isopachous, syntaxial overgrowths). Dolomite is present in minor amounts and is replacing the micrite. This sample has moderate visible porosity (12%), with good interconnectivity. Note the lack of micrite infilling pore space, and the absence of anhydrite and gypsum cements. **x25ppl**
- 2-4 Closer views showing the various types of fauna, grain types, and cements. Plate 2 shows echinoderm fragment (E5) with syntaxial overgrowth (I6), gastropod (F13) with sparry calcite rim (I12), various fauna with micritic envelopes (O11, M3), and fine crystalline dolomite rhombs (P3). Plate 3 shows an echinoderm plate (F13) with syntaxial overgrowth (E10), brachiopod shell fragment (I6) with sparry calcite rim (I5), crinoidal ossicles with micritic envelopes (K2, O2), peloid (I2), ostracod fragment (J7), and fine crystalline dolomite rhombs (Q11). Plate 4 shows a micritized foraminifera (G9), echinoderm fragments (B3, M3, O9) with syntaxial overgrowths (M1, L10), micritic envelopes (G5), and fine crystalline dolomite rhombs (K12, O14). **x100ppl x100ppl x100ppl**

1	2
3	4

1 mm  
x25

400  $\mu$ m  
x63

250  $\mu$ m  
x100

100  $\mu$ m  
x250

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RIGEL SOUTH PIPESTONE 15-09-006-26W1M

A7125

FORMATION: TILSTON BEDS



PLATE#1

010 , 759.06m



**AGAT** Laboratories

THIN SECTION DESCRIPTION: PLATE 2

WELL: 15-09-006-26W1M

TILSTON BEDS

ECHINODERM GRAINSTONE

Porosity: 17.5%

Permeability: 10.3md

SAMPLE SP002P, 760.28m

**1** Overview of a fine grained Echinoderm Grainstone. This limestone consists mainly of calcite, with minor amounts of dolomite, anhydrite, and gypsum. The bioclasts are represented by echinoderm fragments (ossicles, plates), brachiopods, foraminifera, and gastropods (belemnite). Other grain types include peloids and micrite. Primary intergranular porosity has been reduced by minor amounts of calcite cement (isopachous, syntaxial overgrowths), gypsum and anhydrite cements. Dolomite is present in minor amounts and is replacing the micrite. This sample has moderate visible porosity (8%), with moderate interconnectivity. Note the presence of micrite infilling pore space, and anhydrite and gypsum cements occluding pore space (H14). **x25ppl**

**2-4** Higher magnification views showing the various types of fauna, grain types, and cements. Plate 2 shows echinoderm fragments (B10, H14, K2) with syntaxial overgrowths (B10), peloids (M11, J11), micrite infilling pore space (A2, J4), and very fine crystalline dolomite rhombs (E5). Plate 3 shows an echinoderm plate (J12) with syntaxial overgrowth (M11), various crinoidal ossicles and plates (K8, L5), peloids (C1, D10, P5), pore infill micrite (H3), and fine crystalline dolomite rhombs (A8, Q10). Plate 4 shows echinoderm fragments (N7) with syntaxial overgrowths (N7), pore infilling micrite (C9), peloids (K12, B3), and gypsum (J3) and anhydritic cements (N1) occluding pore space (possibly a vug). Note the smaller pore space due to the finer grain sizes, the presence of micrite and anhydrite and gypsum cements. **x100ppl x100ppl x100ppl**

1	2
3	4

1 mm  
x25

400 µm  
x63

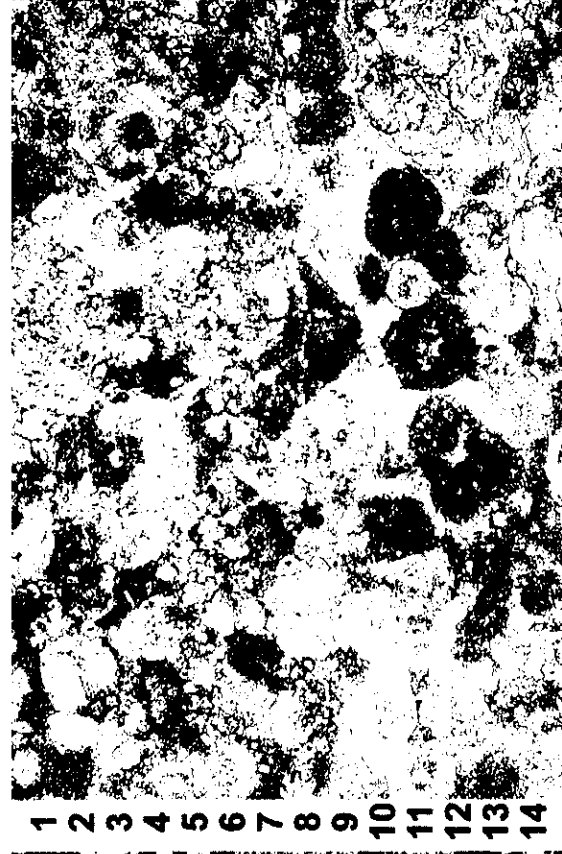
250 µm  
x100

100 µm  
x250

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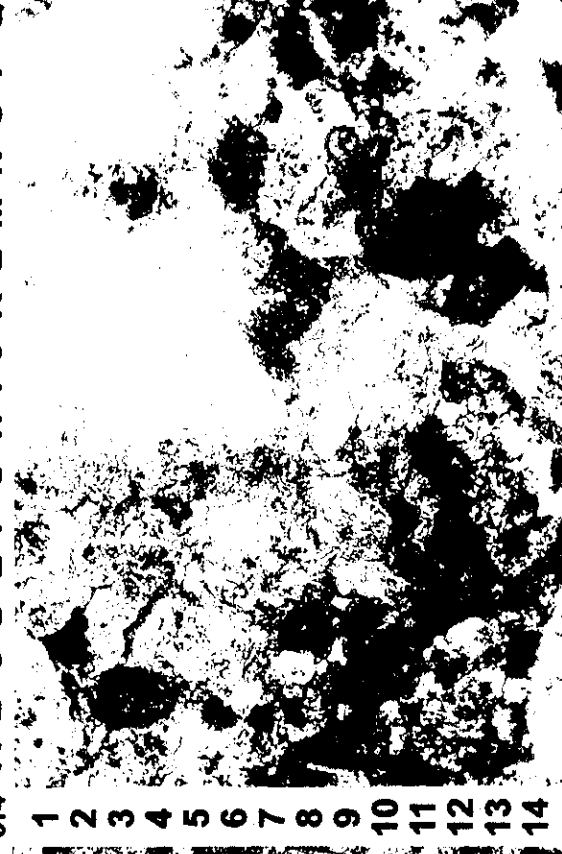
RIGEL SOUTH PIPESTONE 15-09-006-26W1M  
FORMATION: TILSTON BEDS

APRIL 1998  
A7125



A B C D E F G H I J K L M N O P Q

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



PLATE#2

SP002P , 760.28m



**THIN SECTION DESCRIPTION: PLATE 3**

**WELL: 15-09-006-26W1M**

**TILSTON BEDS**

**FXL DOLOMITE**

**Porosity: 14.5%**

**Permeability: 1.04md**

**SAMPLE SP004P, 761.18m**

- 1** Overview of a fine crystalline dolomite with an original texture of echinoderm packstone. This dolomite consists mainly of dolomite, with lesser amounts of gypsum, and minors amounts of anhydrite. Dolomitization is selective in this sample replacing the micritic matrix and leaving behind the bioclasts. The bioclasts have been replaced by gypsum and anhydrite, and are represented by echinoderm fragments (ossicles, plates), and brachiopods. Other grain types include peloids and micrite may have been present but have been obscured by dolomitization. Secondary intercrystalline porosity has been reduced by the gypsum and anhydrite cements. This sample has very poor visible porosity (1%), with poor interconnectivity. Core analysis porosity is 14.5%. This discrepancy between thin section porosity and core analysis porosity suggests that the porosity is represented by microintercrystalline porosity. **x25ppi**
- 2-4** Higher magnification views showing the various types of bioclasts, and cements. Plate 2 shows gypsum replaced echinoderm fragments (H14, D8, L5), and very fine to fine crystalline dolomite rhombs (J12, A5, P6) which has selectively replaced the matrix. Plate 3 shows an fine crystalline dolomite (K8), with gypsum replaced echinoderm fragments (A12). Plate 4 shows echinoderm fragments (M2, H14) replaced by gypsum, and dolomite (C12). Note the lack of visible porosity. **x100ppi**

1	2
3	4

| 1 mm |  
x25

| 400 µm |  
x63

| 250 µm |  
x100

| 100 µm |  
x250

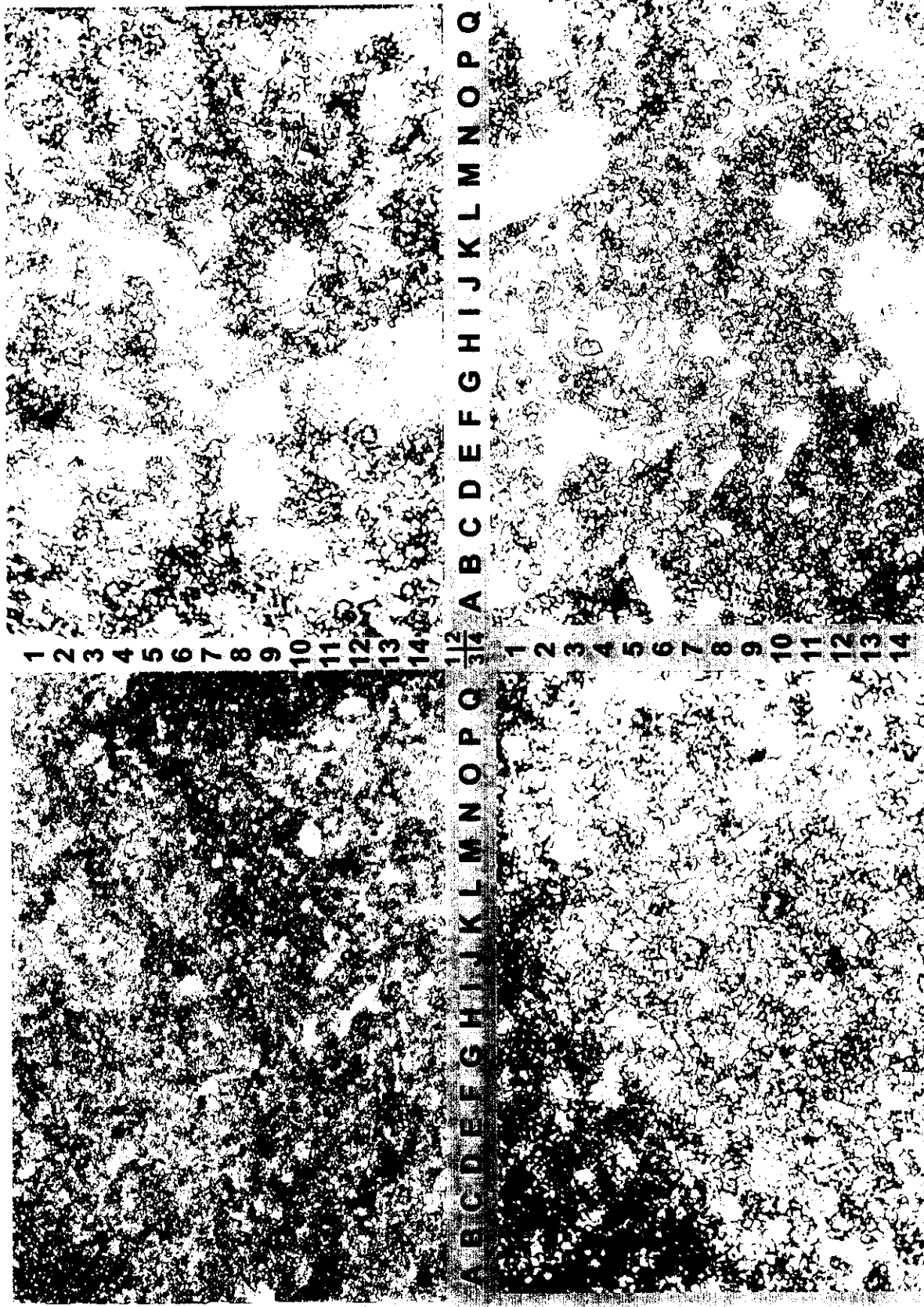
RIGEL OIL & GAS Ltd.

RIGEL SOUTH PIPESTONE 15-09-006-26W1M

FORMATION: TILSTON BEDS

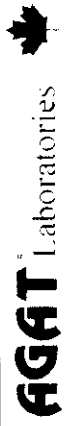
APK 1118

A7125



PLATE#3

SP004P, 761.18m



THIN SECTION DESCRIPTION: PLATE 4

WELL: 03-09-006-26W1M

TILSTON BEDS

ECHINODERM GRAINSTONE

Porosity: 12%

Permeability: 4.07md

SAMPLE SP002P, 772.18m

1 Overview of a fine grained Echinoderm Grainstone. This limestone consists mainly of calcite, with minor amounts of anhydrite, and gypsum, and trace amounts of dolomite and pyrite. The bioclasts are represented by echinoderm fragments (ossicles, plates), brachiopods, foraminifera, ostracods, coral, and gastropods (belemnite). Other grain types include peloids and micrite. Primary intergranular porosity has been reduced by minor amounts of calcite cement (isopachous, syntaxial overgrowths), gypsum and anhydrite cements. Dolomite is present in trace amounts and is replacing the micrite. This sample has moderate visible porosity (8%), with moderate interconnectivity. Note the presence of micrite infilling pore space, and anhydrite and gypsum cements occluding pore space. **x25ppl**

2-4 Closer views showing the various types of bioclasts, grain types, and cements. Plate 2 shows echinoderm fragments (B14), peloids (A13), micrite infilling pore space (A6, H6), anhydrite (L12), and gypsum cements (I14). Plate 3 shows echinoderm plates (O10, E8) with syntaxial overgrowths (I6, L12), pore infilling micrite (C1, B13), and brachiopod shell fragment (G4). Plate 4 shows echinoderm fragments (K2, O13) with syntaxial overgrowths (M11), pore infilling micrite (D4, C13), peloids (M10), and fine crystalline dolomite (I5). **x100ppl x100ppl x100ppl**

1	2
3	4

1 mm  
x25

400 µm  
x63

250 µm  
x100

100 µm  
x250

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RIGEL SOUTH PIPESTONE 03-09-006-26W1M

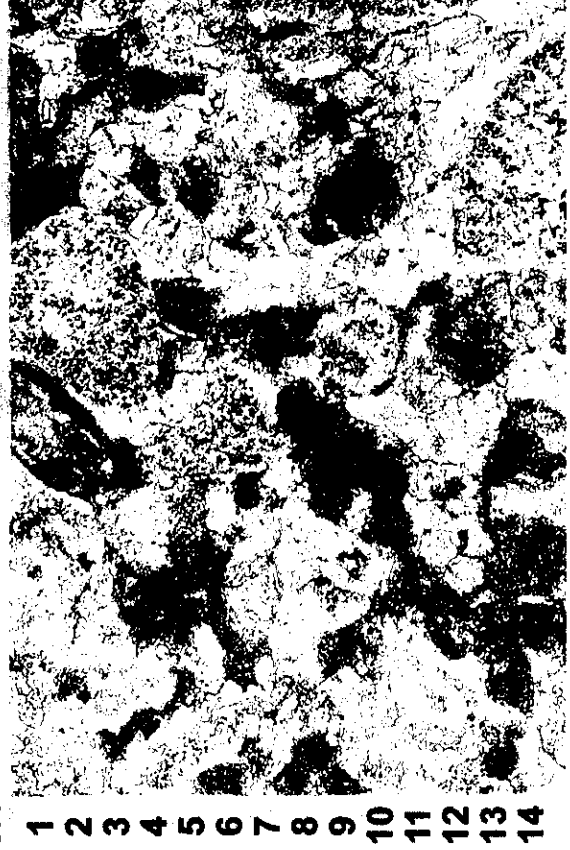
FORMATION: TILSTON BEDS

APRIL 1998

A7125



A B C D E F G H I J K L M N O P Q



THIN SECTION DESCRIPTION: PLATE 5

WELL: 03-09-006-26W1M

TILSTON BEDS

ECHINODERM GRAINSTONE

Porosity: 11.7%

Permeability: 1.52md

SAMPLE SP003P, 773.01m

- 1** Overview of a fine grained Echinoderm Grainstone. This limestone consists mainly of calcite, with minor amounts of dolomite, and trace amounts of authigenic silica. The bioclasts are represented by echinoderm fragments (ossicles, plates), brachiopods, foraminifera, mollusk, ostracod, and gastropods (belemnite). Other grain types include peloids and micrite. Primary intergranular porosity has been reduced by significant amounts of calcite cement (isopachous, syntaxial overgrowths). Dolomite is present in minors amounts and is replacing the micrite and bioclasts. This sample has moderate visible porosity (9%), with moderately poor interconnectivity. Note the presence of micrite infilling pore space, and anhydrite and gypsum cements occluding pore space (H14). **x25ppl**
- 2-4** Higher magnification views showing the various types of bioclasts, grain types, and cements. Plate 2 shows echinoderm fragments (I10, L6) with syntaxial overgrowths (K10, K6), peloids (I6), micrite infilling pore space (C8, L12), and fine crystalline dolomite rhombs (B5). Plate 3 shows echinoderm fragments (F2, O3) with syntaxial overgrowth (E3, N4), coral (P8), mollusk (H7), peloids (J3), pore infilling micrite (O1, G12), and fine crystalline dolomite rhombs (G1). Plate 4 shows echinoderm fragments (I1, M10) with syntaxial overgrowths (L10, F1), gastropod fragment (D7), pore infilling micrite (E7, B14), and peloids (M12). Note the smaller pore space due to the finer grain sizes, the presence of micrite and anhydrite and gypsum cements. **x100ppl x100ppl x100ppl**

1	2
3	4

1 mm  
x25

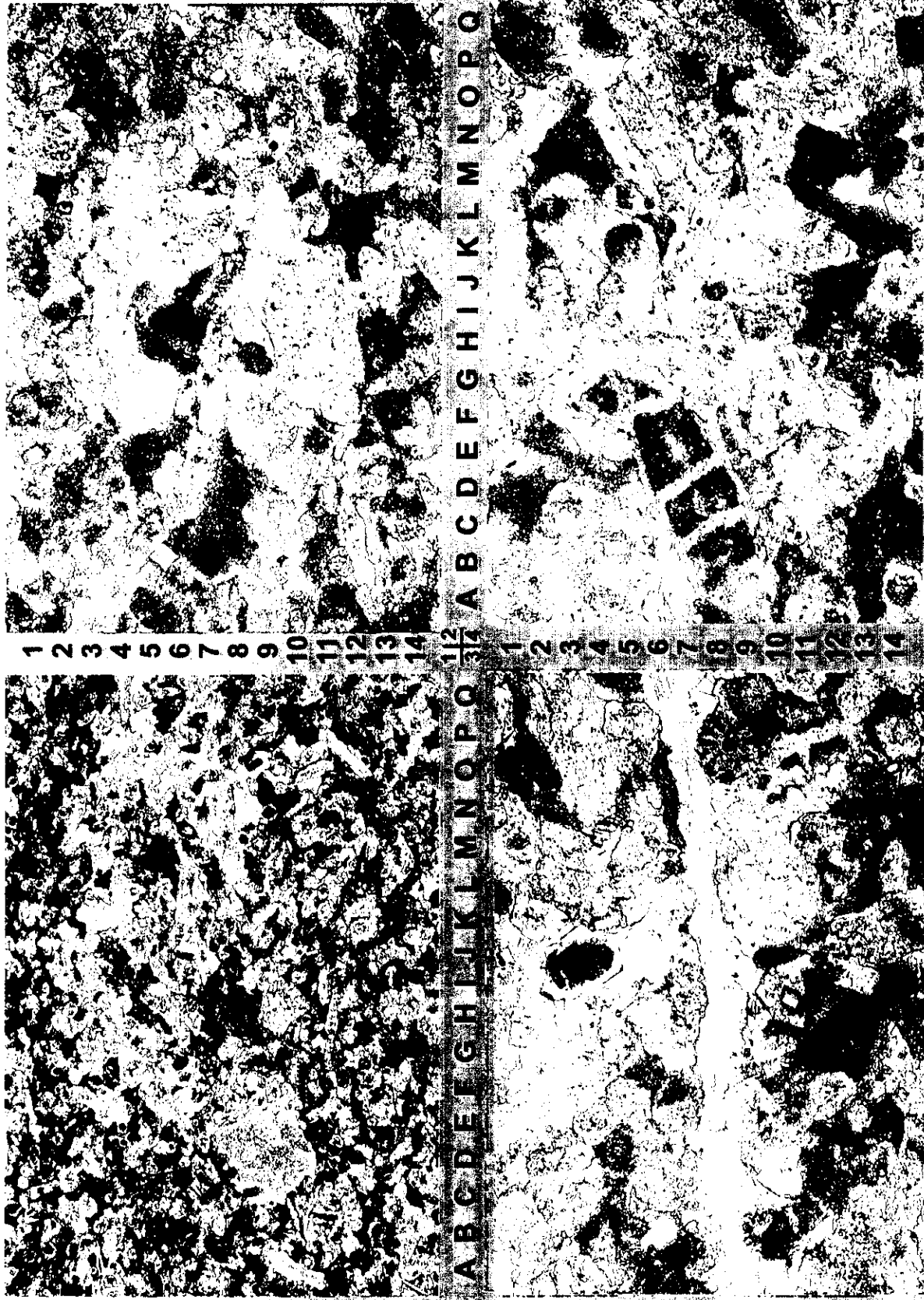
400 µm  
x63

250 µm  
x100

100 µm  
x250

RIGEL OIL & GAS LTD.  
RIGEL SOUTH PIPESTONE 03-09-006-26W1M  
FORMATION: TILSTON BEDS

APRIL 1998  
A7125



THIN SECTION DESCRIPTION: PLATE 6

WELL: 03-09-006-26W1M

TILSTON BEDS

FXL DOLOMITE

Porosity: 10.7%

Permeability: 0.37md

SAMPLE SP005P, 774.59m

- 1 Overview of a fine crystalline dolomite with an original texture of a very fine to coarse grained Echinoderm Packstone. This dolomite consists mainly of dolomite, with lesser amounts of anhydrite, minor amounts of gypsum, and trace amounts of authigenic silica. The bioclasts are represented by echinoderm fragments (ossicles, plates). Other grain types include peloids. Most of the bioclasts have been replaced by anhydrite (O8) and gypsum (E14), leaving behind minor moldic pores. Dolomite occurs as subhedral to euhedral crystals which has not enhanced porosity or permeability. This sample has poor visible porosity (5%), with poor interconnectivity. **x25ppl**
- 2-4 Higher magnification views showing the selective dolomitization of the matrix producing fair intercrystalline porosity (2:L8, 3:Q13, 4:P12) and moldic porosity (2:P7, 3:C7, 4:A3). The majority of the bioclasts (echinoderm fragments) have been replaced by anhydrite (2:I13, 3:J5, 4:G7). Remnants of peloids are seen as dark patches among the dolomite matrix (2:B9, 3:B3). **x100ppl x100ppl x100ppl**

THIN SECTION DESCRIPTION: PLATE 7

1	2
3	4

1 mm  
x25

400 µm  
x63

250 µm  
x100

100 µm  
x250

RIGEL OIL & GAS LTD.

RIGEL SOUTH PIPESTONE 03-09-006-26W1M

FORMATION: TILSTON BEDS

APRIL 1998

A7125



A B C D E F G H I J K L M N O P Q  $1\frac{1}{2}$   $3\frac{1}{4}$



A B C D E F G H I J K L M N O P Q



WELL: 07-16-006-26W1M

TILSTON BEDS

DOLOMITIC LIMESTONE

Porosity: 14.1%

Permeability: 1.7md

SAMPLE #4, 754.70m

- 1 Overview of a dolomitic limestone with an original texture of an fine to coarse grained Echinoderm Packstone. This dolomitic limestone consists mainly of calcite, with lesser amounts of dolomite, minor amounts of anhydrite, and gypsum. The bioclasts are represented by echinoderm fragments (ossicles, plates), brachiopods, coral, and gastropods (belemnite). Other grain types include peloids and micrite. Primary intergranular porosity has been reduced by calcite (isopachous, syntaxial overgrowths), gypsum and anhydrite cements. Dolomite is present in significant amounts replacing the micritic matrix partially. The porosity in this sample is characterized by microporosity and moldic porosity. It has moderate visible porosity (13.5%), with moderately poor interconnectivity. Note the presence of micrite infilling pore space, and anhydrite and gypsum cements occluding pore space. **x25ppl**
- 2-4 Higher magnification views showing the various bioclasts, grain types, and cements. Plate 2 shows echinoderm fragments (P7, B1), micrite infilling pore space (Q13, A9), gypsum occluding dissolution vugs (J1), and very fine crystalline dolomite rhombs (P12). Plate 3 shows an echinoderm fragments (F14, B3), gastropod chamber (M3), micrite infilling pore space (G2, A10), fine crystalline dolomite rhombs (M8, H10), and moldic porosity (L10). Plate 4 shows echinoderm fragments (F11, C3), pore infilling micrite (C1, M1), peloids (K12, B3), and moldic porosity (H11). Note the smaller pore space due to the finer grain sizes and micrite, the presence of micrite and anhydrite and gypsum cements. **x100ppl x100ppl x100ppl**

1	2
3	4

1 mm  
x25

400 µm  
x63

250 µm  
x100

100 µm  
x250

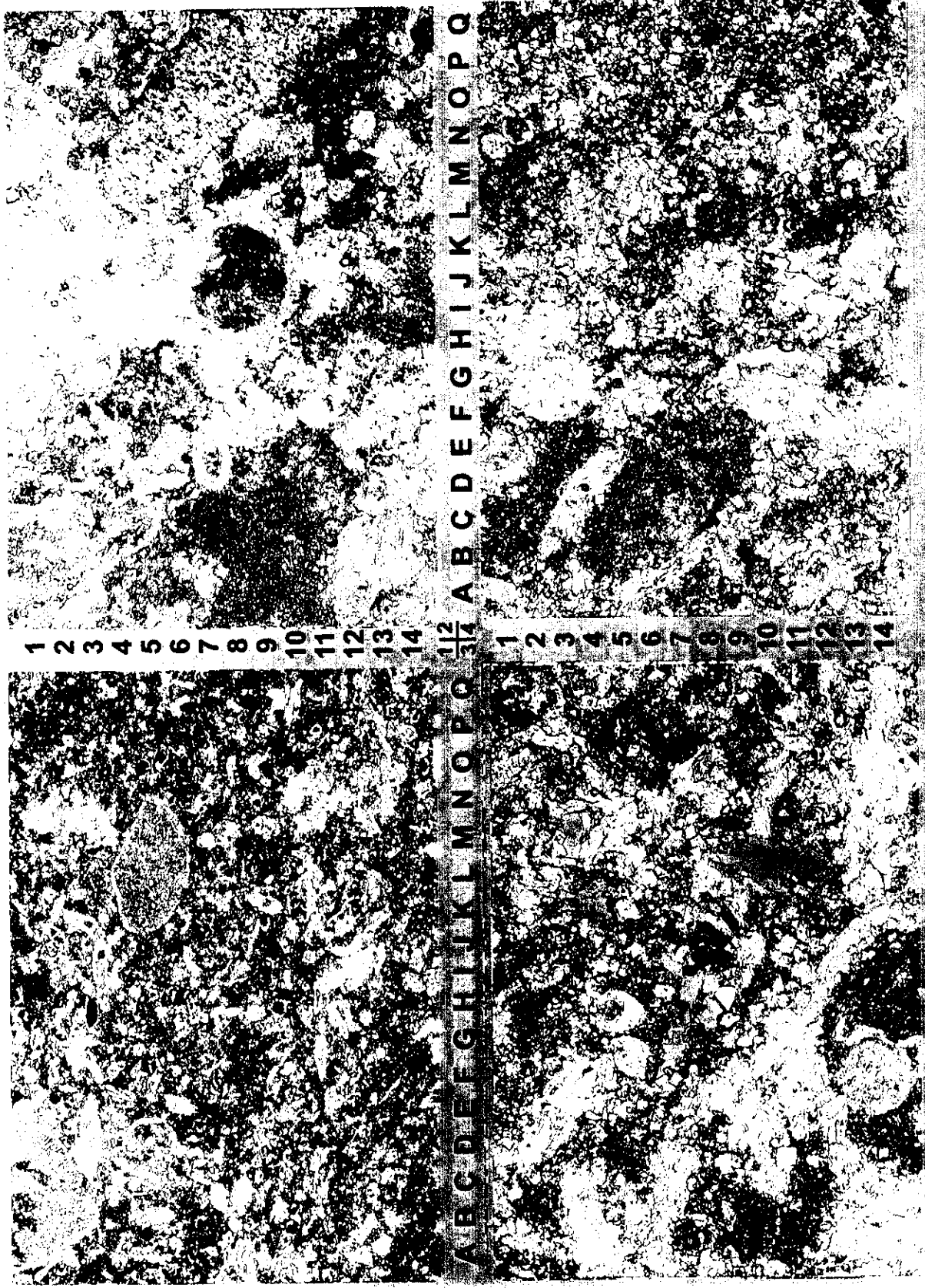
RIEDEL & GAGL LTD.

SCEPTRE SOUTH PIPESTONE 07-16-006-26W1M

FORMATION: TILSTON BEDS

APKAL 1570

A7125



PLATE#7

#4, 754.70m



AGAT Laboratories

**THIN SECTION DESCRIPTION: PLATE 8**

**WELL: 07-16-006-26W1M**

**TILSTON BEDS**

**FXL DOLOMITE**

**Porosity: 25.6%**

**Permeability: 47md**

**SAMPLE #10, 757.60m**

- 1** Overview of a fine crystalline dolomite with an original texture of an fine grained Peloidal Grainstone. This dolomite consists mainly of dolomite, with minor amounts of authigenic silica. The bioclasts are represented by echinoderm fragments (ossicles, plates). Other grain types include peloids. Pervasive dolomitization of the micritic matrix and peloids produced good intercrystalline porosity. This sample has very good visible porosity (24%), with good interconnectivity. **x25ppl**
- 2-4** Higher magnification views showing pervasive dolomitization with peloidal ghosts left behind (2:B1, 3:E5). Good intercrystalline porosity is the result of the pervasive dolomitization (2:H14, 3:G1, 4:D5). Note tight patches of dolomite (4:I8) may be related to bioclasts. **x100pppl x100pppl x100pppl**

1	2
3	4

| 1 mm |  
x25

| 400 µm |  
x63

| 250 µm |  
x100

| 100 µm |  
x250

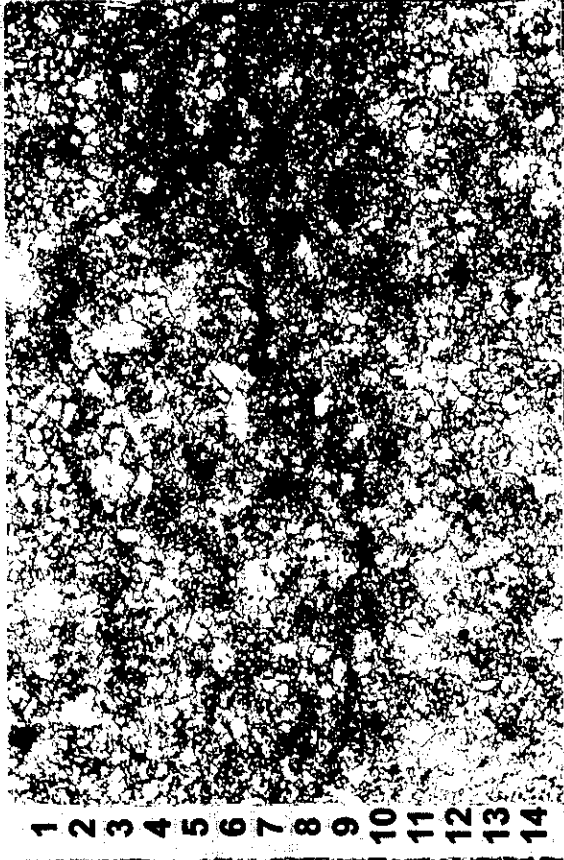
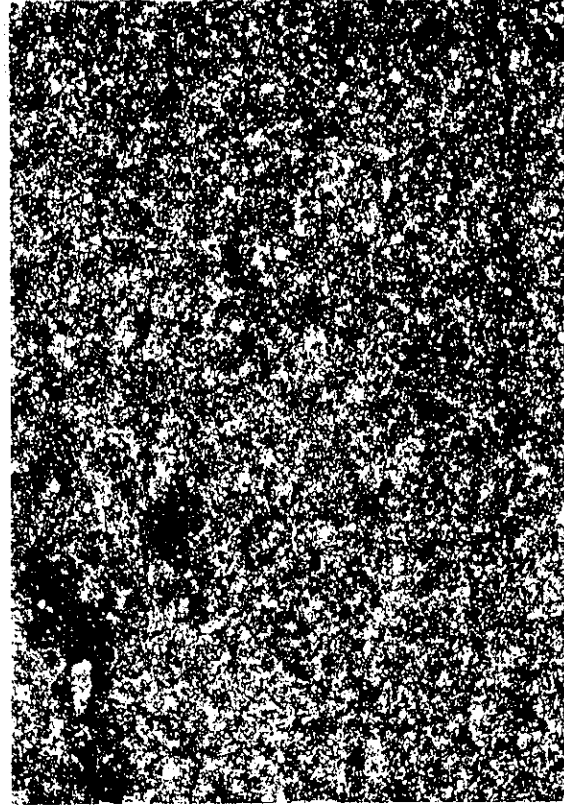
RIGEL OIL & GAS LTD.

APRIL 1998

SCEPTRE SOUTH PIPESTONE 07-16-006-26W1M

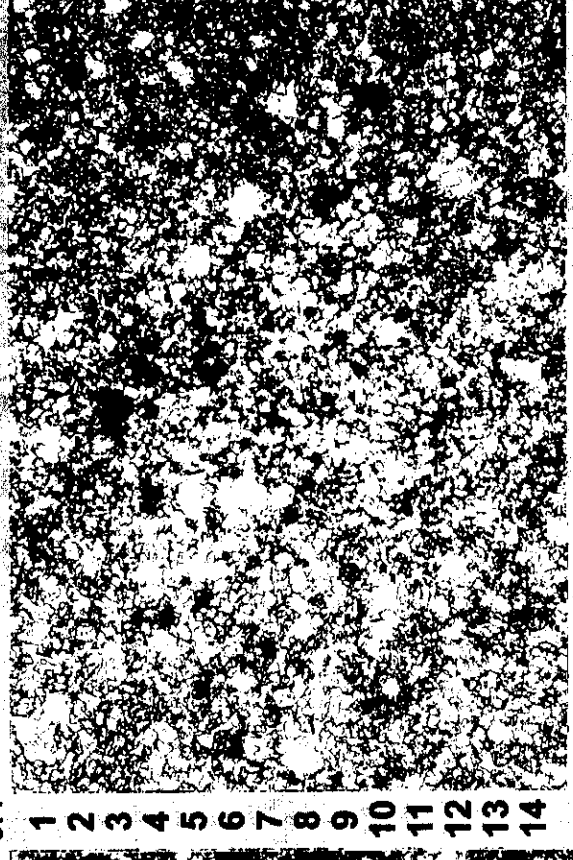
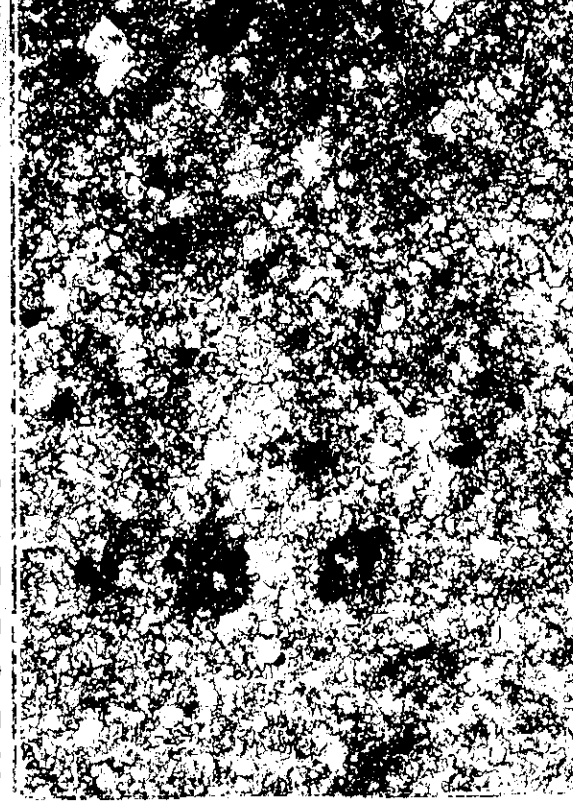
A7125

FORMATION: TILSTON BEDS



A B C D E F G H I J K L M N O P Q

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



THIN SECTION DESCRIPTION: PLATE 9

WELL: 07-16-006-26W1M

TILSTON BEDS

BIOCLASTIC/PELOIDAL GRAINSTONE

Porosity: 16.9%

Permeability: 15md

SAMPLE #14, 759.40m

- 1 Overview of a fine to coarse grained Bioclastic/Peloidal Grainstone. This limestone consists mainly of calcite, with minor amounts of authigenic silica, dolomite, anhydrite, and gypsum. The bioclasts are represented by echinoderm fragments (ossicles, plates) (B9), gastropods (belemnite), and coral (H11). Other grain types include peloids and micrite. Primary intergranular porosity has been reduced by calcite (isopachous -A1, syntaxial overgrowths -D10), gypsum (L13) and anhydrite (M12) cements, and authigenic silica (E14). Dolomite is present in minors amounts and is replacing the micrite (L7). This sample has moderate visible porosity (10%), with moderate interconnectivity. **x25ppl**
- 2 Higher magnification view showing internal structure of a coral with several types of cements present. The internal pores are occluded by authigenic silica (A10, G12), and isopachous sparry calcite (I11, P14). The coral structure is also replaced by quartz (M3). **x100pppl**
- 3-4 Closer views of coarse grained peloids (3:G7, 4:J9), echinoderm plates (3:L3, 4:G13), with syntaxial overgrowths (3:K6), dolomite replacing micrite (3:D4), and stylolite between peloids and micrite (4:D1). **x100pppl x100pppl**

1	2
3	4

| 1 mm |  
x25

| 400 µm |  
x63

| 250 µm |  
x100

| 100 µm |  
x250

REGEL OIL & GAS LTD.

SCEPTRE SOUTH PIPESTONE 07-16-006-26W1M

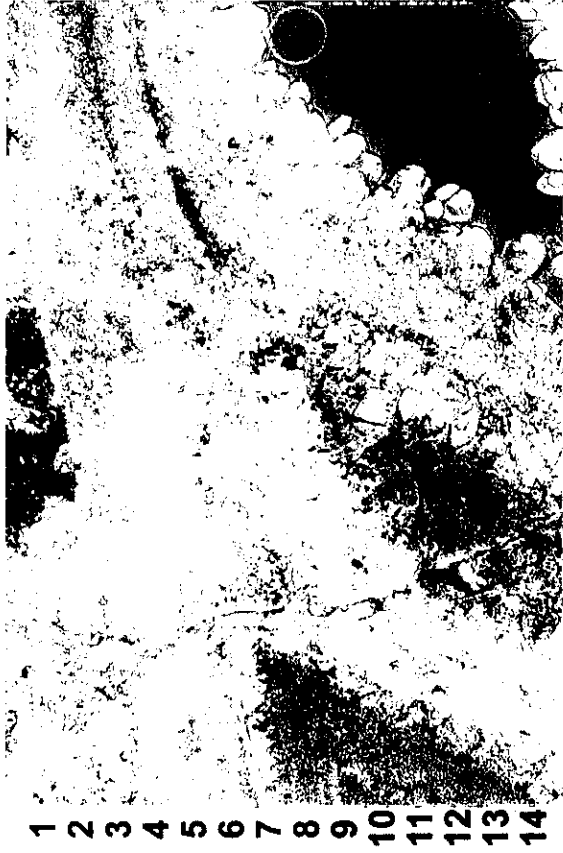
FORMATION: TILSTON BEDS

APRIL 1998

A7125



A B C D E F G H I J K L M N O P Q



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



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



A B C D E F G H I J K L M N O P Q



AGAT Laboratories

PLATE# 9

#14, 759.40m

**THIN SECTION DESCRIPTION: PLATE 10**

**WELL: 06-09-006-26W1M**

**TILSTON BEDS**

**FXL DOLOMITE**

**Porosity: 13.27%**

**Permeability: 0.91md**

**SAMPLE SP002R, 773.97m**

- 1** Overview of a fine crystalline dolomite with an original texture of a very fine to coarse grained Echinoderm Packstone. This dolomite consists mainly of dolomite, with lesser amounts of anhydrite. The bioclasts are represented by echinoderm fragments (ossicles, plates), and brachiopod and gastropod shells. Other grain types include peloids. Most of the bioclasts have been replaced by anhydrite (C5), leaving behind minor moldic pores. Dolomite occurs as subhedral to euhedral crystals which has not enhanced porosity or permeability. This sample has moderate visible porosity (12%), with poor interconnectivity. **x25ppl**
- 2-4** Higher magnification views showing the selective dolomitization of the matrix producing poor intercrystalline porosity (2:B8, 3:E12, 4:D5), and moderate moldic porosity (2:O12). The majority of the bioclasts (echinoderm fragments) have been replaced by anhydrite (2:K8, 3:K4, 4:K8). Remnants of peloids are seen as dark patches among the dolomite matrix (2:E14, 3:A8, 4:K2). **x100ppl x100ppl x100ppl**

1	2
3	4

**1 mm**  
**x25**

**400  $\mu$ m**  
**x63**

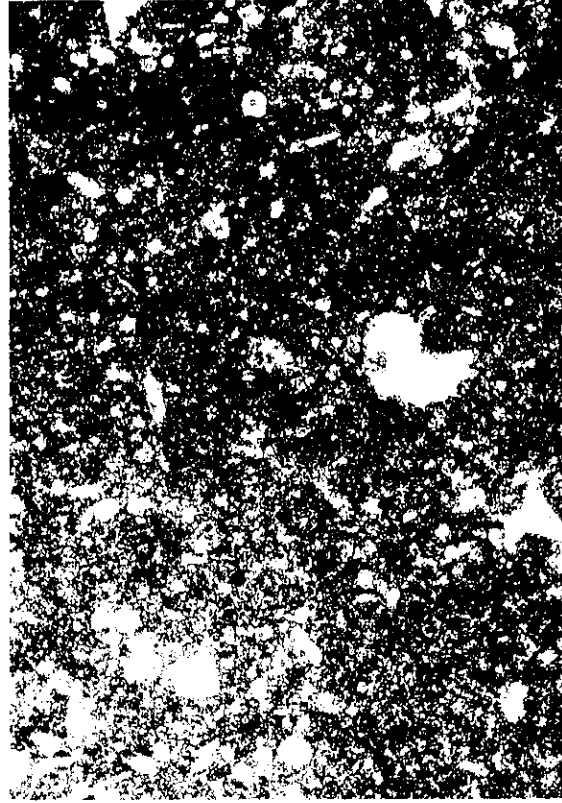
**250  $\mu$ m**  
**x100**

**100  $\mu$ m**  
**x250**

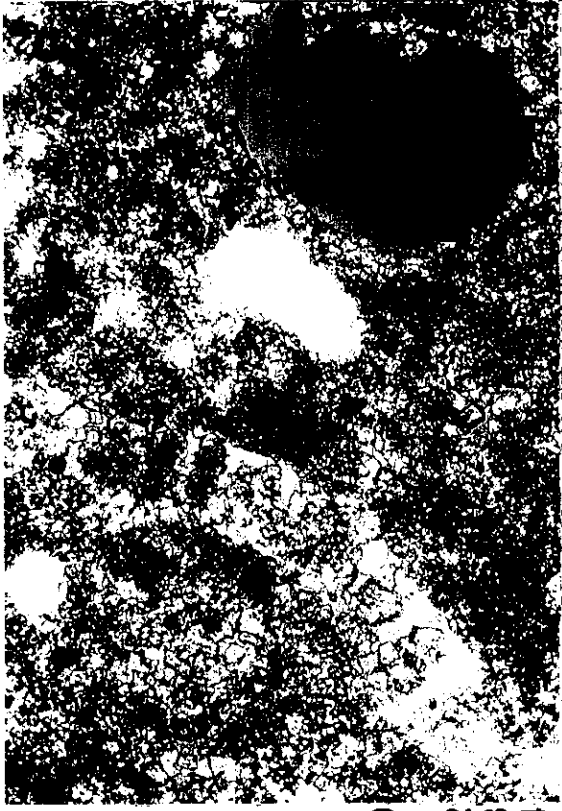
RIGEL OIL & GAS LTD.

RIGEL SOUTH PIPESTONE 06-09-009-26W1M  
FORMATION: TILSTON BEDS

APRIL 1998  
A7125



A B C D E F G H I J K L M N O P Q



A B C D E F G H I J K L M N O P Q



AGAT

PLATE # 10  
SP002P , 773.97m

THIN SECTION DESCRIPTION: PLATE 11

WELL: 06-09-006-26W1M

TILSTON BEDS

FXL DOLOMITE

Porosity: 22.2%

Permeability: 13.5md

SAMPLE 020, 776.71m

- 1** Overview of a fine crystalline dolomite with an original texture of a very fine to coarse grained Echinoderm Wackestone. This dolomite consists mainly of dolomite, with lesser amounts of gypsum, and trace amounts of anhydrite. The bioclasts are represented by echinoderm fragments (ossicles, plates). Other grain types include peloids. Most of the bioclasts have been replaced by gypsum (N2), leaving behind minor moldic pores. Dolomite occurs as subhedral to euhedral crystals which have enhanced porosity and permeability. This sample has good visible porosity (18%), with good interconnectivity. **x25ppl**
- 2-4** Higher magnification views showing selective dolomitization of the matrix producing good intercrystalline porosity (2:C3, 3:Q10, 4:J12) and moldic porosity (2:A10). The majority of the bioclasts (echinoderm fragments) have been replaced by gypsum (3:F11, 4:E10). Remnants of peloids are seen as dark patches among the dolomite matrix (3:B2, 4:B7). **x100ppl**

1	2
3	4

1 mm  
x25

400 µm  
x63

250 µm  
x100

100 µm  
x250

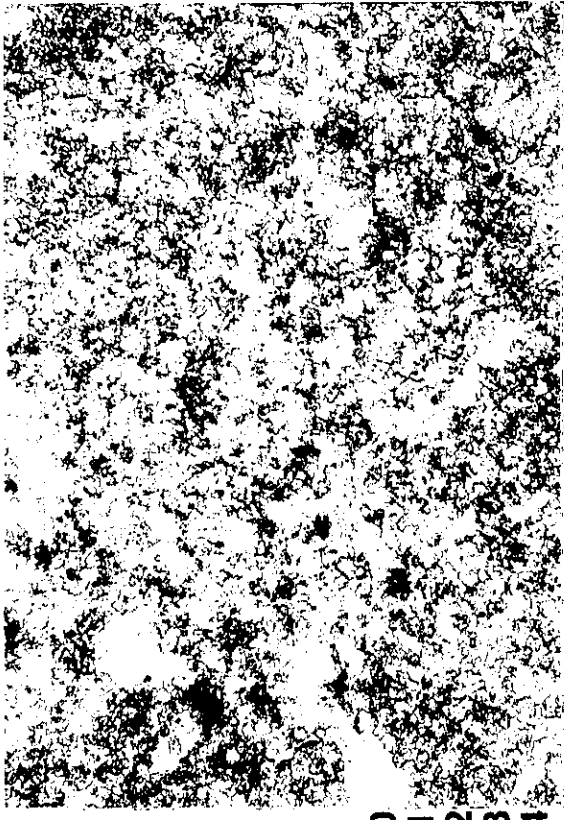
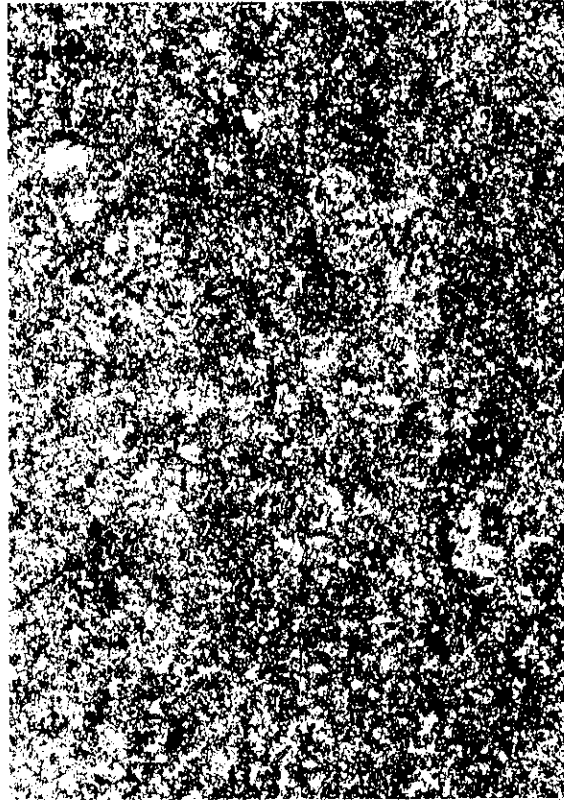
RIGEL OIL & GAS LTD.

APRIL 1978

RIGEL SOUTH PIPESTONE 06-09-009-26W1M

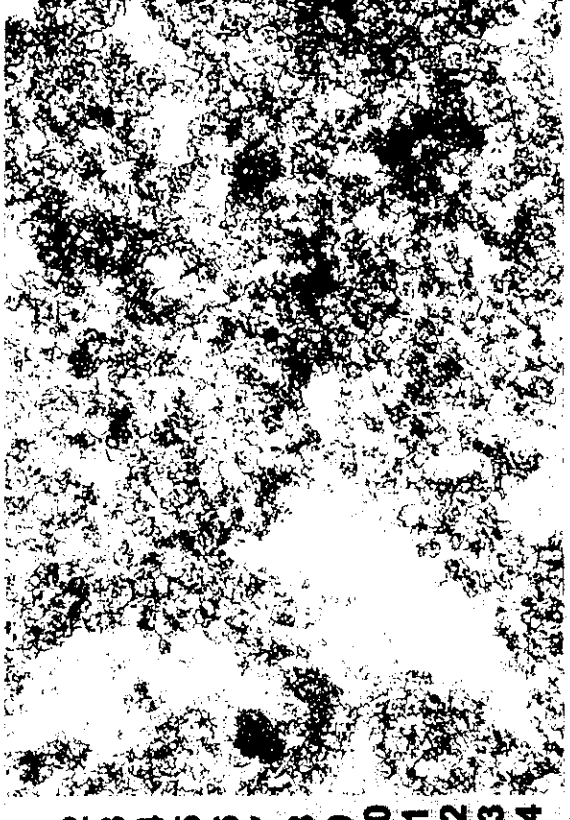
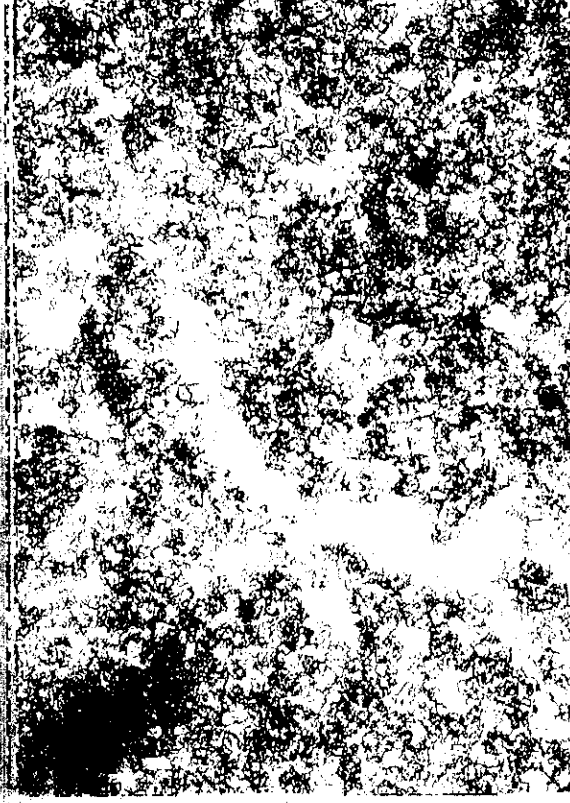
A7125

FORMATION: TILSTON BEDS



A B C D E F G H I J K L M N O P Q

A B C D E F G H I J K L M N O P Q



**AGAT** Laboratories



PLATE # 11

020, 776.71m

THIN SECTION DESCRIPTION: PLATE 12

WELL: 06-09-006-26W1M

TILSTON BEDS

DOLOMITIC LIMESTONE

Porosity: 11.6%

Permeability: 0.32md

SAMPLE SP006P, 778.46m

**1** Overview of a dolomitic limestone with an original texture of an fine to medium grained Echinoderm Packstone. This dolomitic limestone consists mainly of calcite, with lesser amounts of dolomite, and gypsum, and minor amounts of anhydrite. The bioclasts are represented by echinoderm fragments (ossicles, plates), brachiopods, coral, and gastropods (belemnite). Other grain types include peloids and micrite. Primary intergranular porosity has been reduced by calcite (isopachous, syntaxial overgrowths), gypsum and anhydrite cements. Dolomite is present in significant amounts partially replacing the micritic matrix. The porosity in this sample is characterized by microporosity and moldic porosity. It has moderate visible porosity (8%), with poor interconnectivity. Note the presence of micrite infilling pore space, and anhydrite and gypsum cements occluding pore space. **x25ppi**

**2-4** Higher magnification views showing the various bioclasts, grain types, and cements. Plate 2 shows echinoderm fragments (L3, N11), syntaxial overgrowths (H3), micrite infilling pore space (J8, P2), and very fine crystalline dolomite rhombs (B9). Plate 3 shows echinoderm fragments (D11), micrite infilling pore space (E13), peloid (M11), fine crystalline dolomite rhombs (N8, D8), and gypsum occluding vuggy porosity (M5). Plate 4 shows echinoderm fragments (B5, B13), pore infilling micrite (K2, P8), peloids (K10), and gastropod (L7). Note the smaller pore space due to the finer grain sizes and micrite, the presence of micrite and anhydrite and gypsum cements. **x100ppi x100ppi x100ppi**

1	2
3	4

1 mm  
x25

400 µm  
x63

250 µm  
x100

100 µm  
x250

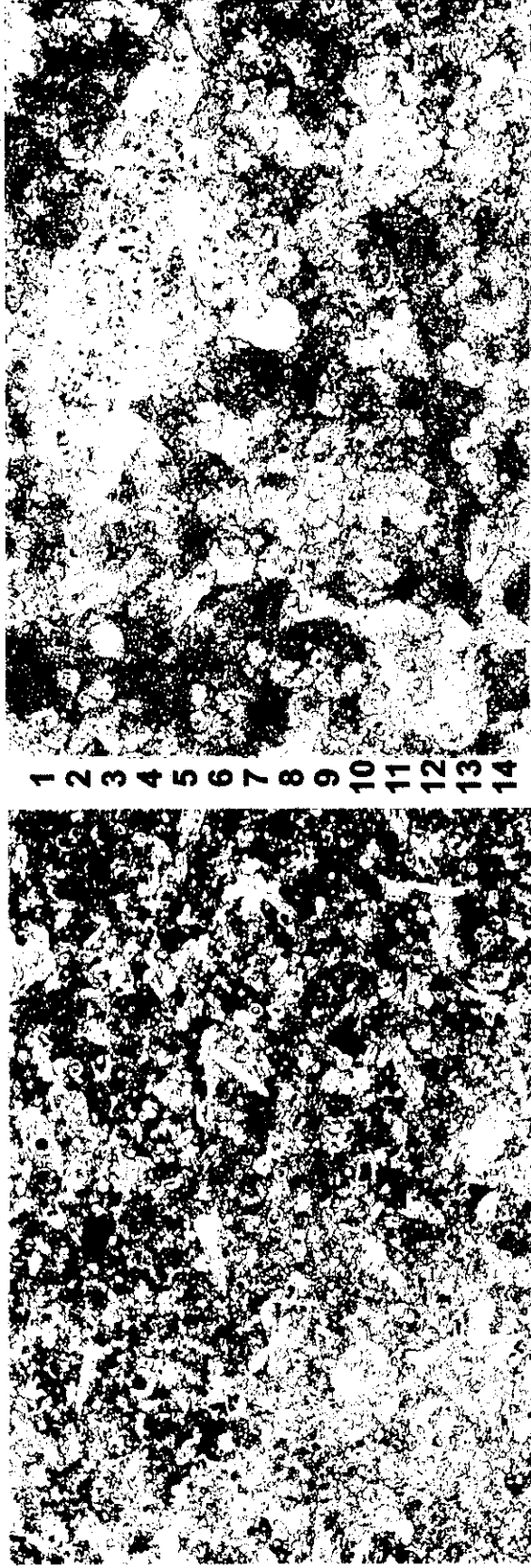
RIGEL OIL & GAS LTD.

APRIL 1998

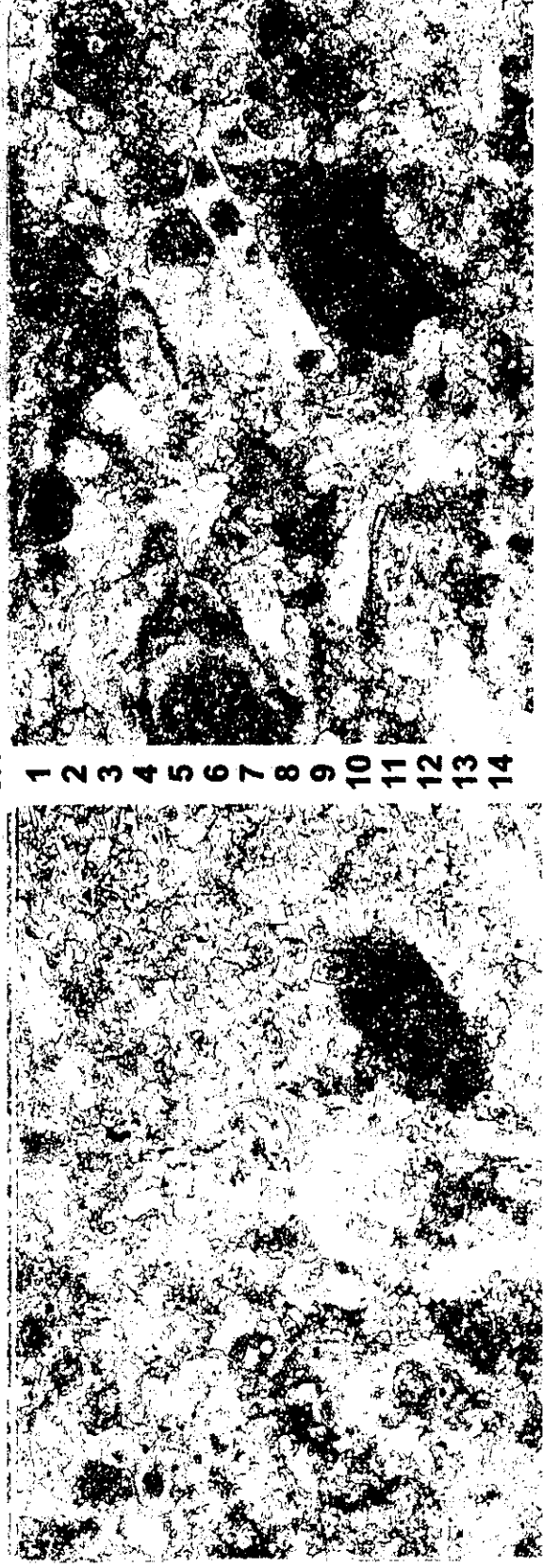
RIGEL SOUTH PIPESTONE 06-09-009-26W1M

A7125

FORMATION: TILSTON BEDS



A B C D E F G H I J K L M N O P Q  $1\frac{1}{2}$  1 2 3 4 5 6 7 8 9 10 11 12 13 14



## SECTION II

**Rigel Oil and Gas Ltd.**  
**Petrographic and Reservoir Study**

**Work Order No. A-7125**  
**April, 1998**

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**SECTION II**  
**CORE LOGS**

# RIGEL SOUTH PIPESTONE PROV.

15-09-006-26w1m

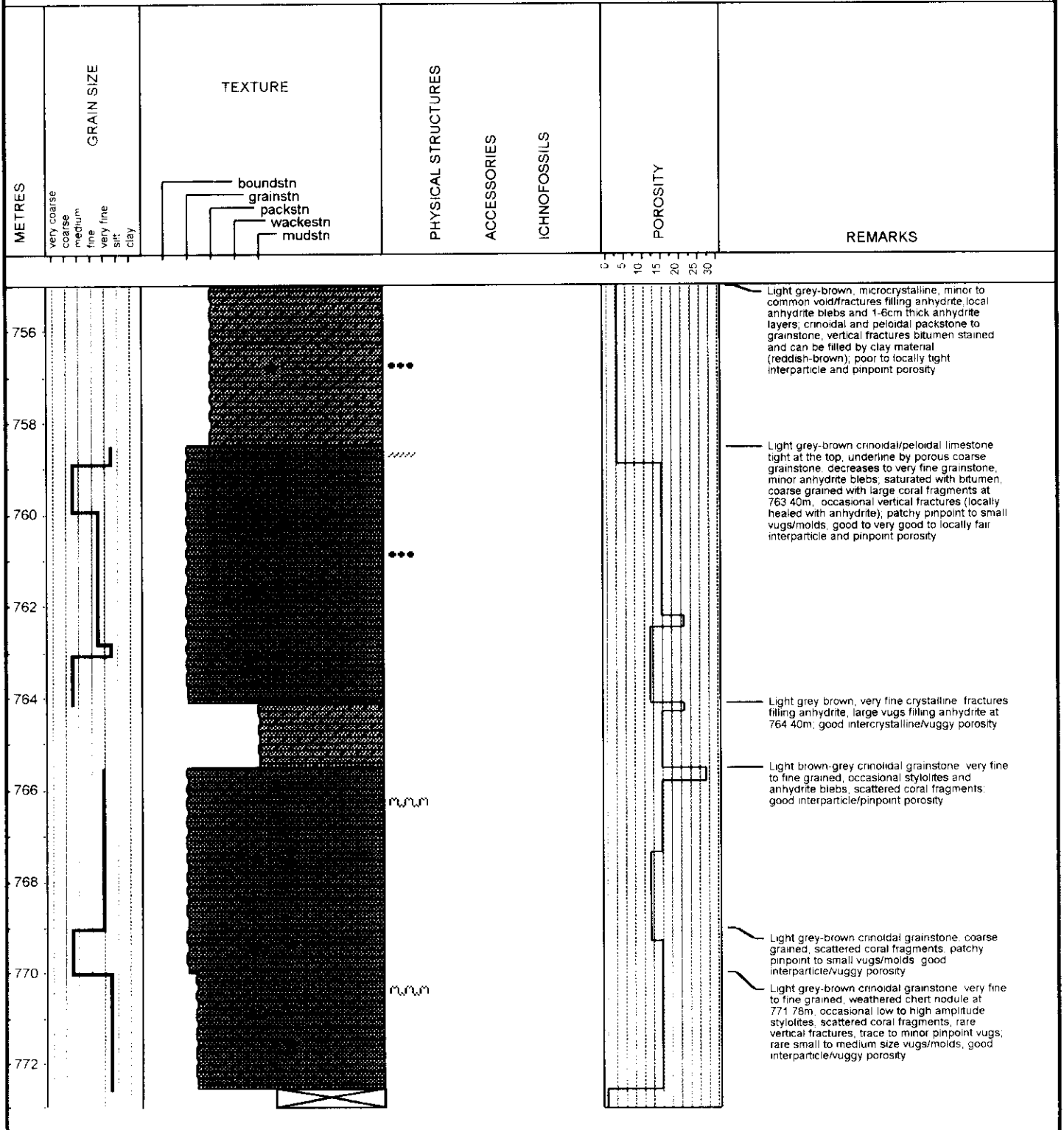
Date logged: April 14, 1998

Logged by:

Ground: 0.00 m KB: 437.40 m

Remarks: Tilston Beds

CN#1 755.00 - 773.00m



# RIGEL SOUTH PIPESTONE PROV.

03-09-006-26w1m

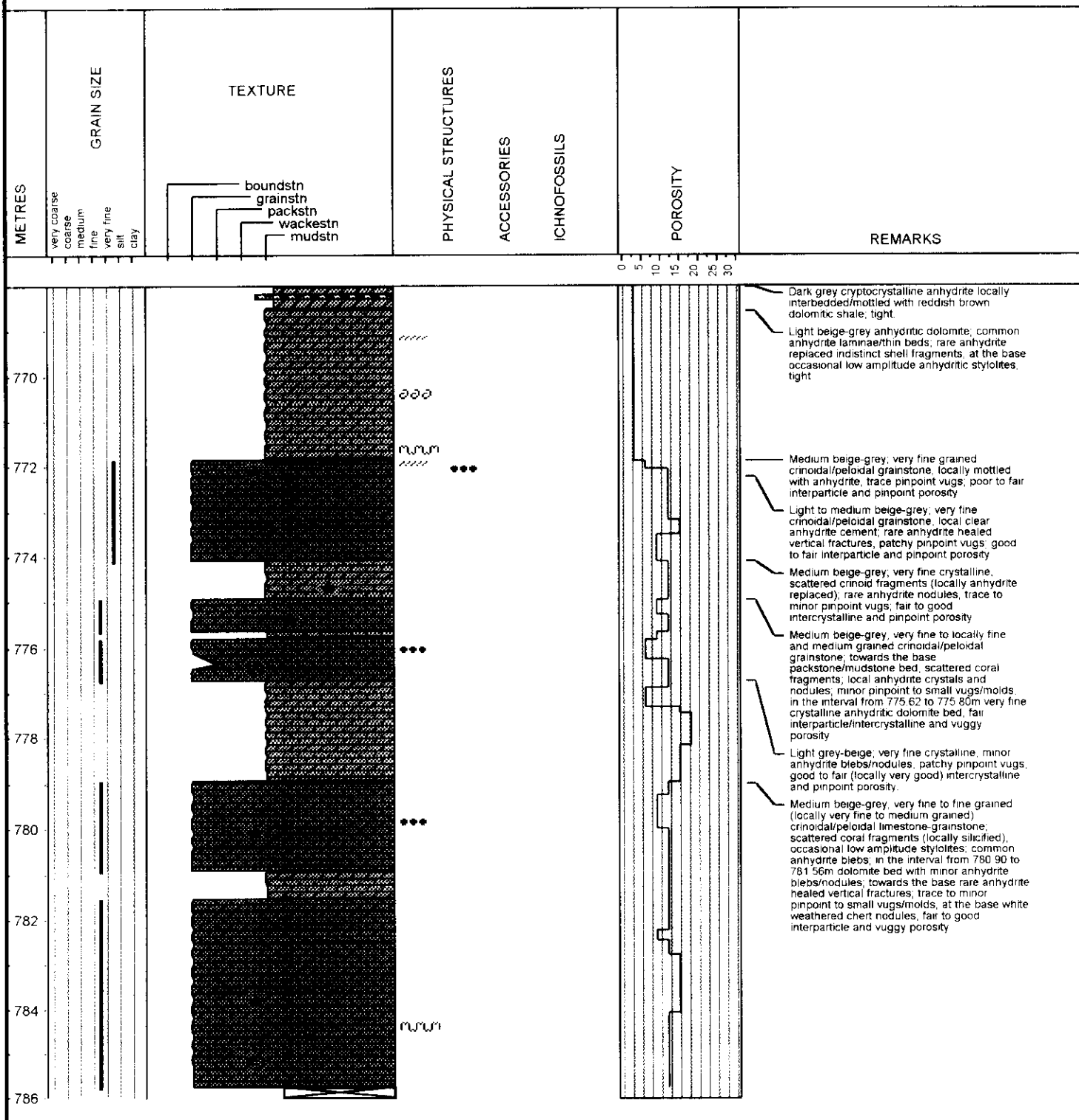
Date logged: April 17, 1998

Logged by:

Ground 0.00 m KB: 438.60 m

Remarks: Tilston Beds

CN#1 768.00 - 786.00m



# SCEPTRE SOUTH PIPESTONE

07-16-006-26w1m

Date logged: April 15, 1998

Logged by:

Ground: 0.00 m KB: 437.60 m

Remarks: Tilston Beds

CN#1 752.25 - 770.50m

METRES	GRAIN SIZE	TEXTURE	PHYSICAL STRUCTURES	ACCESSORIES	ICHOFOSSILS	POROSITY	REMARKS
	very coarse coarse medium fine very fine silt clay	boundstn grainstn packstn wackestn mudstn				0 5 10 15 20 25 30	
754							Light grey; very fine to fine grained crinoidal/peloidal grainstone; trace to minor clear anhydrite crystals; scattered to minor coral fragments; patchy pinpoint to small vugs/molds; good to fair interparticle and vuggy porosity.
756							
758							Light grey; very fine crystalline; occasional low amplitude stylolites; trace to minor pinpoint vugs; at the top scattered small to medium size vugs/molds; excellent intercrystalline porosity.
760							Light grey; very fine to fine grained (locally very fine to coarse grained) crinoidal/peloidal grainstone; occasional low to high amplitude stylolites; trace to minor coral fragments; trace silica replaced bioclast fragments; patchy pinpoint to small vugs/molds; towards the top scattered medium to large size molds; occasional anhydrite healed vertical fractures; at the base rare open vertical fractures; good to fair interparticle and vuggy/moldic porosity.
762							
764							
766							
768							
770							

# RIGEL SOUTH PIPESTONE PROV.

06-09-006-26w1m

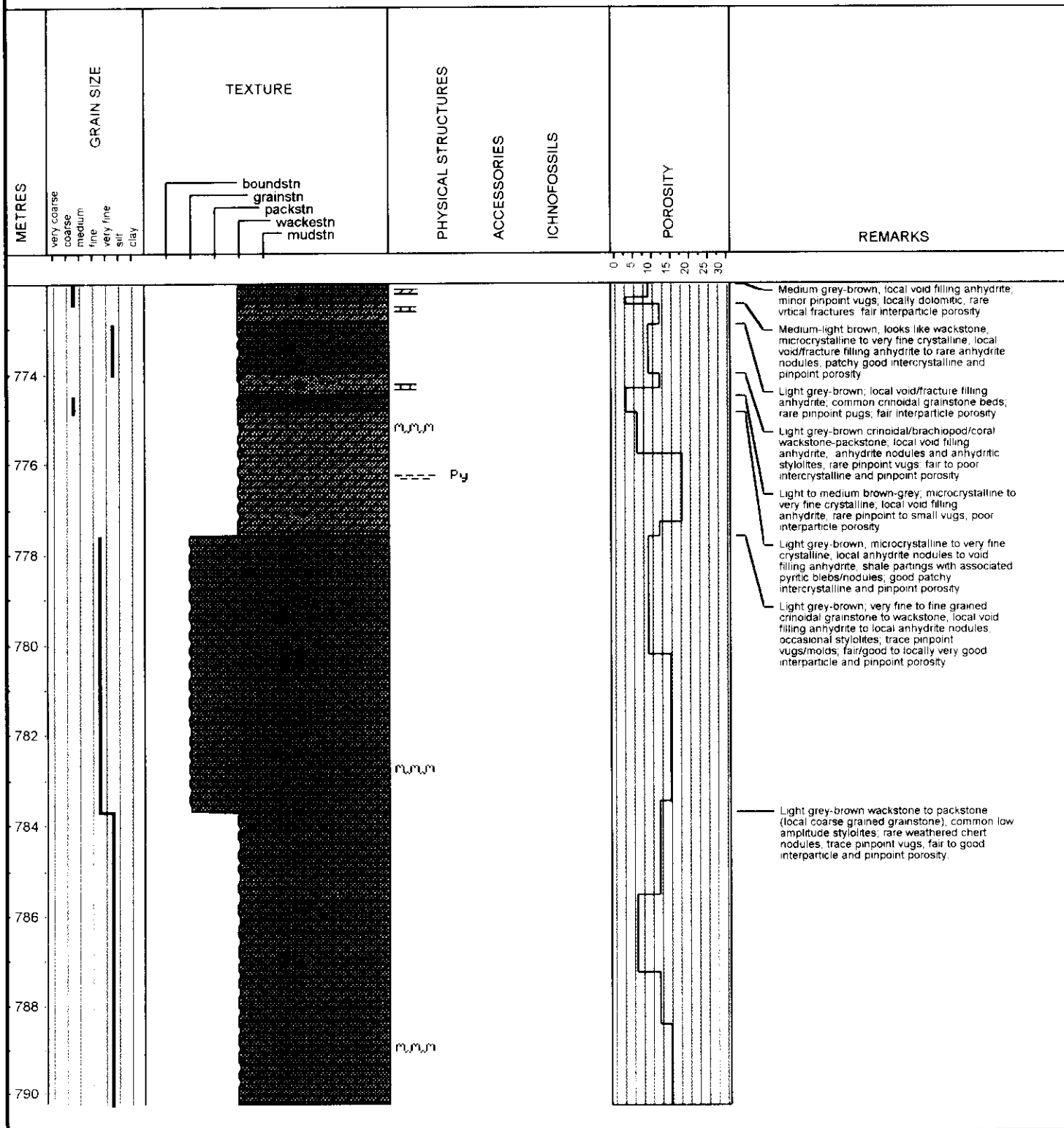
Date logged: April 14, 1998

Logged by:

Ground: 0.00 m KB: 437.50 m

Remarks: Tilston Beds

CN#1 772.00 - 790.25m



LEGEND

LITHOLOGY



LIMESTONE



DOLOSTONE



Calcareous Dolst

PHYSICAL STRUCTURES



Stylolites

LITHOLOGIC ACCESSORIES



Shale Lamina



Calcareous



Dolomitic



Pyrite

FOSSILS



Brachiopods



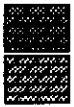
Corals (solitary)



Crinoids

## LEGEND

### LITHOLOGY



LIMESTONE



Dolomitic shale



Cherty Lst



Gypsum/Anhyd.

DOLOSTONE

### PHYSICAL STRUCTURES



Stylolites

### LITHOLOGIC ACCESSORIES



Shell Fragments



- Peloids



- Anhydritic

### FOSSILS



Corals (solitary)



- Crinoids

## SECTION III

**Rigel Oil and Gas Ltd.  
Petrographic and Reservoir Study**

**Work Order No. A-7125  
April, 1998**

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**SECTION III**  
**MERCURY INJECTION POROSIMETRY STUDY**

**MERCURY INJECTION  
POROSIMETRY STUDY**

**Various Locations  
Tilston Beds Formation**

Prepared for:  
**RIGEL OIL AND GAS LIMITED**

1900, 255 - 5th Avenue S.W.  
Calgary, AB  
T2P 3G6

Prepared by:

**AGAT Laboratories**  
3700 - 21st Street N.E.  
Calgary, Alberta  
T2E 6V6

Telephone: (403) 299-2185

**Work Order 98RE1587  
May, 1998**

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4. Discussion of Results
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Figure 8: Sample 4: Mercury Injection Capillary Pressure Plot

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Figure 11: Sample 5: Standard Plots

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Figure 13: Sample 6: Standard Plots

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Figure 15: Sample 7: Standard Plots

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Figure 17: Sample 8: Standard Plots

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## SECTION SUMMARY

Eight samples representing various locations in the Tilston Beds Formation were submitted for Mercury Injection Porosimetry testing to evaluate the pore structure of good or poor producing zones.

The porosities obtained from the mercury injection analysis were found to range from 12.52 to 25.64 %. The *Winland* gas permeabilities were found to range from 0.31 to 431.65 md.

The results of the mercury injection test indicates that the peak pore throat radius of the samples ranged from 0.14 to 15.74 microns.

In comparing the samples from the good and poor zones , it can be seen that samples 1, 4, 5, & 8 (poor zones) have broader pore size distributions with approximately 50 to 85% of their pore space being accessed by pore throats less than 0.5 micron. Samples 2, 3, 6, & 7 (good zones) are seen to have less than 30% of their pore space accessed by pore throats less than 0.5 micron with narrower pore size distributions.

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## EXPERIMENTAL PROCEDURE

For the current study, eight samples from the Tilston Beds Formation representing 4 different locations were submitted for Mercury Injection Porosimetry testing.

The samples were gently cleaned in a reflux soxhlet apparatus with toluene followed by a 50/50 mixture of acetone/methanol and then oven dried at 80°C.

The samples were individually placed in a penetrometer assembly and evacuated. The penetrometer was then filled with mercury at a hydrostatic head of approximately 10 kPa. The volume of mercury required to fill the penetrometer was measured and the bulk volume of the samples was determined by subtracting this mercury volume from the known volume of the empty penetrometer bulb.

The pressure on the mercury surrounding the sample was then raised in preset increments up to 414 MPa (60,000 psi). After stabilization at each pressure step, the volume of mercury injected into the sample was recorded. At 414 MPa the mercury was assumed to have invaded 100% of the pore space and therefore the maximum intrusion volume, at this pressure, was assumed to be equal to the pore volume of the sample.

The wetting phase saturation corresponding to each pressure step is defined as the volume of the wetting phase (vacuum) divided by the total pore volume:

$$S_v = 1 - \frac{V_{Hg}}{PV}$$

where  $S_v$  = vacuum saturation  
 $V_{Hg}$  = volume of mercury injected  
 $PV$  = total pore volume

The pressure steps were then plotted versus their corresponding saturations to provide the drainage capillary pressure curves.

For each capillary pressure increment, the corresponding pore throat entry radius can be calculated via the equation:

$$r = \frac{2 \sigma \cos \theta}{P_c}$$

where  $\sigma$  = the interfacial tension  
= 480 dynes/cm for a mercury/vacuum system  
 $\theta$  = the contact angle  
= 140° for a mercury/vacuum system  
 $P_c$  = the capillary pressure (kPa)

From the corresponding wetting phase saturation, the percentage of the pore space controlled by a given pore throat radius can be determined. This data is presented as the Cumulative Intrusion Volume.

The "Normalized Incremental Intrusion Volume" is calculated by dividing the mercury volume injected at each pressure increment by the maximum incremental intrusion volume.

The mercury capillary pressure curve may be converted to an air-water capillary pressure curve by the application of the pore throat radii equation. That is, with  $r$  constant at a given saturation, the ratio of the capillary pressures for the different fluids would yield:

$$\frac{(P_c)_1}{(P_c)_2} = \frac{\sigma_1 \cos \theta_1}{\sigma_2 \cos \theta_2}$$

where the subscripts denote the different fluids.

Assuming a mercury-vacuum system (where  $\sigma_1 = 480$  dynes/cm and  $\theta_1 = 140^\circ$ ) and an air-water system (where  $\sigma_2 = 72$  dynes/cm and  $\theta_2 = 0^\circ$ ), the above relation yields a ratio of 5.1 (this is an industry standard based on the contact angle and interfacial tension for mercury and brine). It is recommended that this ratio be used with caution since it has been shown (by Brown<sup>1</sup>) that the ratio varies from formation to formation and even from sample to sample. The air-brine equivalent capillary pressure curve was generated by dividing the mercury pressure by this ratio (5.1) and plotting against the wetting phase saturation.

An estimate of the gas permeability of the samples is derived from the pore throat size distribution data through the use of the "*Winland  $R_{35}$* " formula. This proprietary equation is based on the pore throat radius associated with the 35% intrusion volume ( $R_{35}$ ) and the porosity derived from the mercury injection tests.

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1. Brown, H. W., "*Capillary Pressure Investigations*", AIME Petroleum Transactions, Vol. 192, pp. 67-74, 1951.

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## DISCUSSION OF RESULTS

Results of Mercury Injection Porosimetry testing are presented in graphical formats which include; a mercury capillary pressure curve, plots of pore throat size versus cumulative intrusion volume, pore throat size versus normalized pore volume distribution, and a mercury-based air/brine capillary pressure curve (refer to Figures 2 through 17).

A summary of the Petrophysical Properties are presented in Table 1 and the Mercury Injection test results are summarized in Table 2. The routine porosities and gas permeabilities were found to range from 13.20 to 27.86% and from 0.447 to 278.320 md. The mercury porosities were found to range from 12.52 % for Sample 5 (well Sceptre South Pipestone 07-16-006-26W1M) to 25.64 % for Sample 6 (same well).

Samples 1 & 2 from the South Pipestone Prov. 06-09-006-26W1M well, were found to have their peak pore radius occurring at 1.26 & 1.78, respectively. Sample 1 representing the poor zone, is seen to have a bimodal pore system with just over 50% of its pore space being accessed by pore throats less than 0.5 micron. Sample 2 (good zone) is seen to have a broad unimodal pore system with less than 30% of its pore space accessed by pore throats less than 0.5 micron.

Samples 3 & 4 from the Rigel South Pipestone Prov. 03-09-006-26W1M well, were found to have their peak pore radius occurring at 4.09 & 0.14, respectively. Sample 3 representing the good zone, is seen to have a broad unimodal pore system with less than 30% of its pore space accessed by pore throats less than 0.5 micron. Sample 4 (poor zone) is seen to have a broader pore system with just over 80% of its pore space being accessed by pore throats less than 0.5 micron.

Samples 5 & 6 from Sceptre South Pipestone 07-16-006-26W1M well were found to have their peak pore radius occurring at 1.07 & 2.51, respectively. Sample 5 representing the poor zone, is seen to have evidence of a bimodal pore system with just under 60% of its pore space being accessed by pore throats less than 0.5 micron. Sample 6 (good zone) is seen to have an unimodal pore system with less than 10% of its pore space accessed by pore throats less than 0.5 micron.

Samples 7, & 8 from Rigel South Pipestone Prov. 15-09-006-26W1M Well were found to have their peak pore radius occurring at 15.74 & 0.90, respectively. Sample 7 representing the good zone, is seen to have an unimodal pore system with just over 20% of its pore space accessed by pore throats less than 0.5 micron. Sample 8 (poor zone) is seen to have a very broad pore system with just under 70% of its pore space being accessed by pore throats less than 0.5 micron.

From the above results, it can be seen that the samples from the poor producing zones are characterized by having a broader pore size distribution with between 50 to 85% of their pore space being accessed by pore throats less than 0.5 micron. The samples from the good producing zones are characterized by narrower pore size distributions with less than 30% of their pore space being accessed by pore throats less than 0.5 micron.

The indicated irreducible water saturations from the mercury-based air/brine capillary pressure curves (generally taken at 50 psi or 345 kPa to compare to porous plate results) were found to range from 6.66 to 77.08 %.

The calculated permeabilities from the "*Winland R<sub>35</sub>*" relation ranged from 0.31 to 431.65 md. When gas permeability was plotted versus the *Winland* gas permeability, the following relation was noted (refer to Figure 1):

$$k_g = 0.9437 k_{wg}^{0.8884}; r^2 = 0.9115$$

where  $k_g$  = gas permeability (md)  
 $k_{wg}$  = Winland gas permeability (md)

The above equation may be used to predict the gas permeability of samples from mercury porosimetry results. It is also an indication of whether the gas permeability is affected by fractures or damaged during the coring process. The reader is reminded that the **Winland** relation was developed for a specific formation and may not apply to the samples in this study. This equation is only valid for the range of permeability tested in this study.

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**AGAT Laboratories** would like to acknowledge the following employees for their contributions to this report:

Ian Cowan, P.Eng., B.Sc.  
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Jim Lui, P.Eng., B.Sc.  
Reservoir Analyst, Reservoir Engineering Division

Marwan Barasi, B.Sc.  
Reservoir Analyst, Reservoir Engineering Division

**Special Core Laboratory Staff:**

Gary Hecker, Laboratory Supervisor  
Mike Prefontaine  
Derek Kulikowski  
Robert Kulikowski

Report Prepared by: \_\_\_\_\_  
Marwan Barasi, B.Sc.  
Reservoir Analyst

**Table 1**  
**Summary of Petrophysical Properties**

Sample	Depth (m)	Well Name	Location	Grain Density (kg/m <sup>3</sup> )	Porosity (%)	k <sub>g</sub> (md)
1	773.97	South Pipestone Prov.	06-09-006-26W1M	2855	13.24	1.150
2	776.81	South Pipestone Prov.	06-09-006-26W1M	2830	24.55	10.863
3	772.18	Rigel South Pipestone Prov.	03-09-006-26W1M	2703	13.81	4.197
4	774.59	Rigel South Pipestone Prov.	03-09-006-26W1M	2854	13.20	0.447
5	754.70	Sceptre South Pipestone	07-16-006-26W1M	2739	13.26	0.919
6	757.60	Sceptre South Pipestone	07-16-006-26W1M	2822	27.86	45.540
7	759.06	Rigel South Pipestone Prov.	15-09-006-26W1M	2690	18.42	278.324
8	761.18	Rigel South Pipestone Prov.	15-09-006-26W1M	2791	19.18	1.485

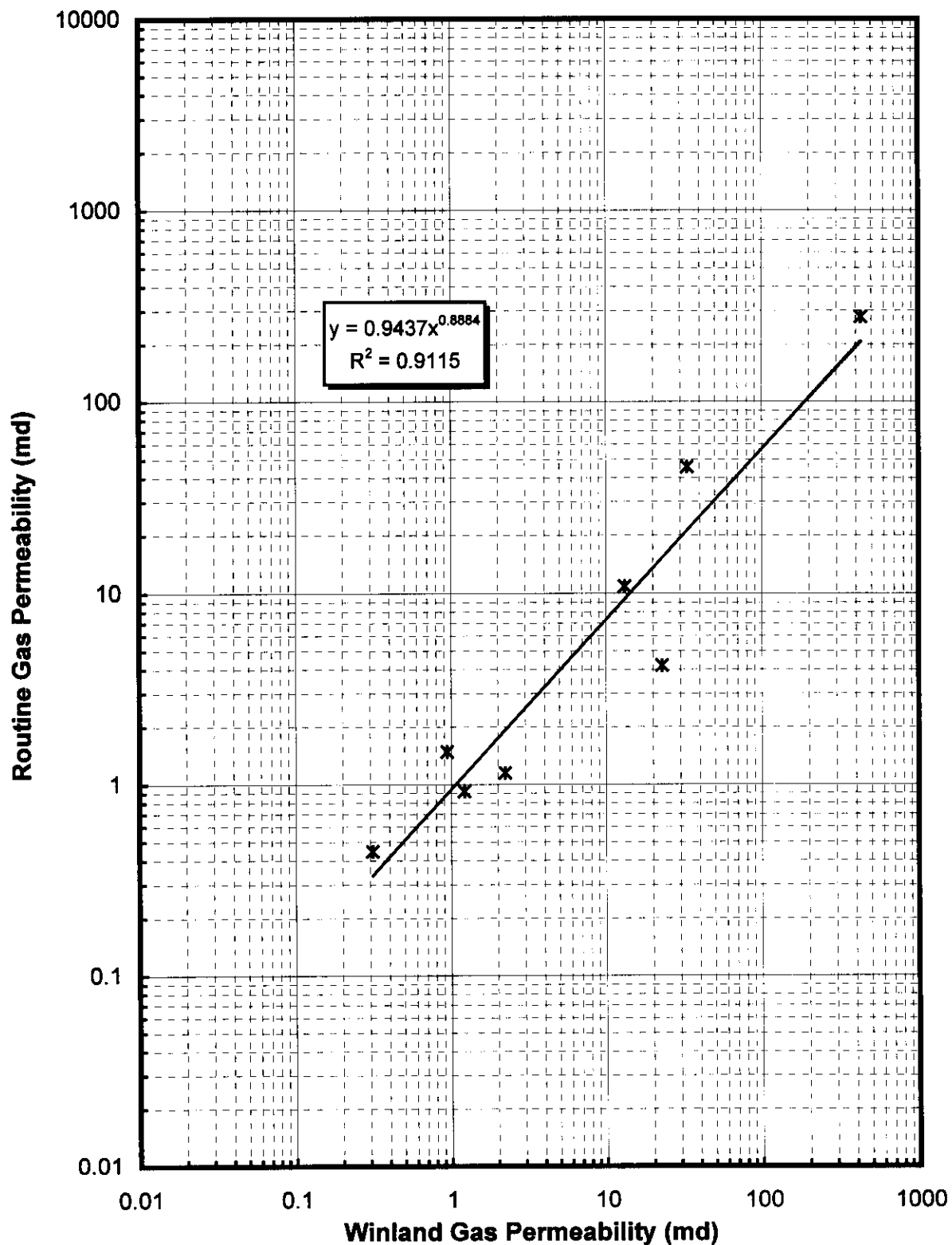
k<sub>g</sub> - gas permeability

**Table 2**  
**Mercury Injection Porosimetry Results**

Sample	Well Name	Location	Depth (m)	Mercury Porosimetry Analysis					
				Microporosity < 0.5 micron (%)	Grain Density (kg/m <sup>3</sup> )	Porosity (%)	Winland k <sub>g</sub> (md)	r <sub>p</sub> (microns)	A/B S <sub>wi</sub> (%)
1	South Pipestone Prov.	06-09-006-26W1M	773.97	54	2829	12.93	2.23	1.2583	50.82
2	South Pipestone Prov.	06-09-006-26W1M	776.81	29	2846	24.31	13.21	1.7779	24.80
3	Rigel South Pipestone Prov.	03-09-006-26W1M	772.18	28	2701	12.90	22.95	4.0876	26.31
4	Rigel South Pipestone Prov.	03-09-006-26W1M	774.59	80	2810	12.90	0.31	0.1419	77.08
5	Sceptre South Pipestone	07-16-006-26W1M	754.70	57	2728	12.52	1.22	1.0686	53.66
6	Sceptre South Pipestone	07-16-006-26W1M	757.60	8	2828	25.64	33.19	2.5137	6.66
7	Rigel South Pipestone Prov.	15-09-006-26W1M	759.06	21	2709	17.96	431.65	15.7360	20.43
8	Rigel South Pipestone Prov.	15-09-006-26W1M	761.18	66	2751	15.40	0.94	0.8969	61.25

k<sub>g</sub> - gas permeability  
r<sub>p</sub> - peak pore throat radius  
A/B - air/brine equivalent capillary pressure

**Figure 1**  
**Routine Gas Permeability vs Winland Gas Permeability**



Company: Rigel Oil and Gas Ltd.  
Well: South Pipestone Prov. 06-09-006-26W1M  
Formation: TILSTON BEDS

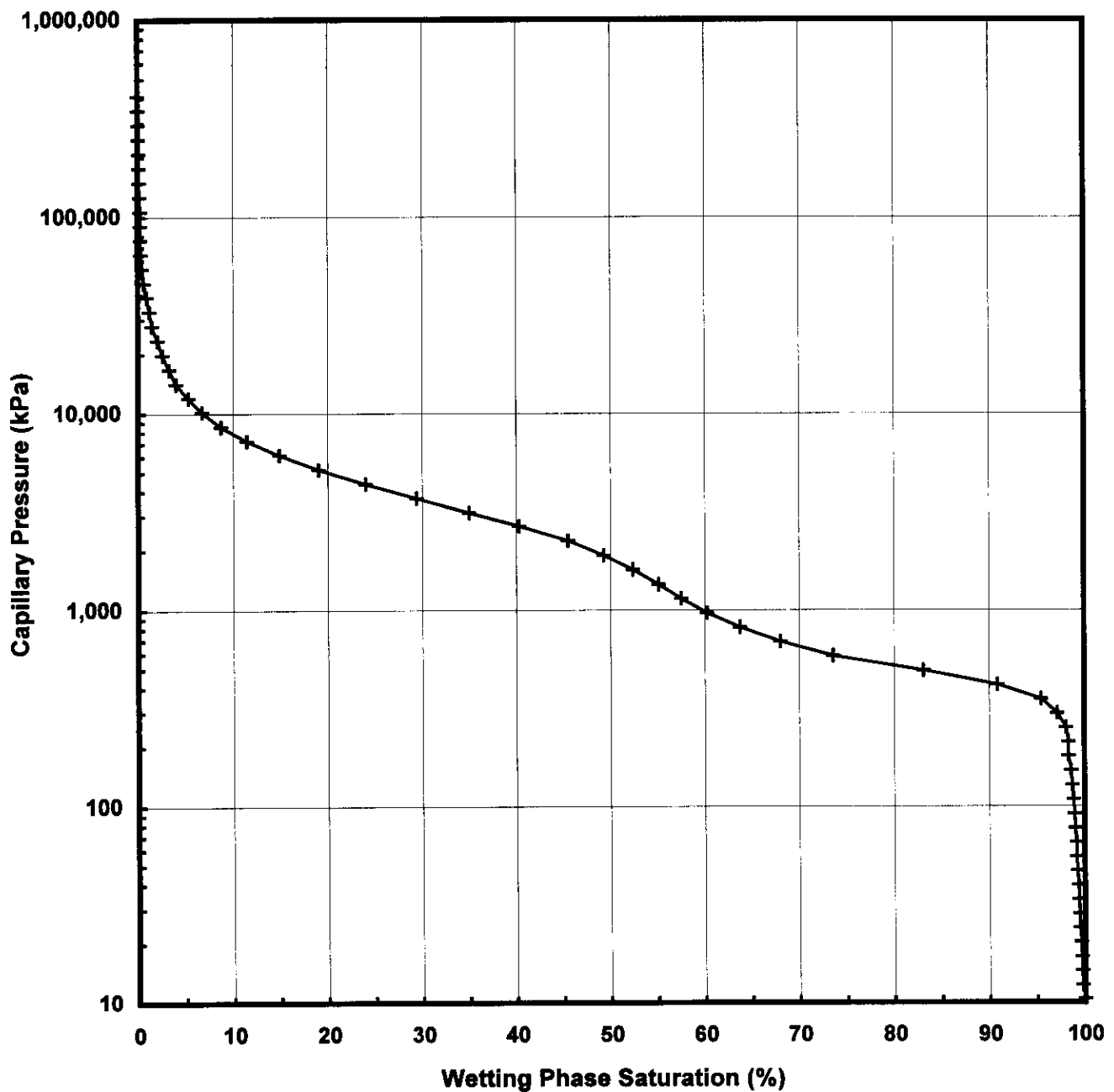
File: 98RE1587  
Date: 4/21/98

## FIGURE #2

### MERCURY INJECTION CAPILLARY PRESSURE

Sample: #1  
Depth: 773.97 m

Winland Perm: 2.2324 md  
Hg Porosity: 12.93 %

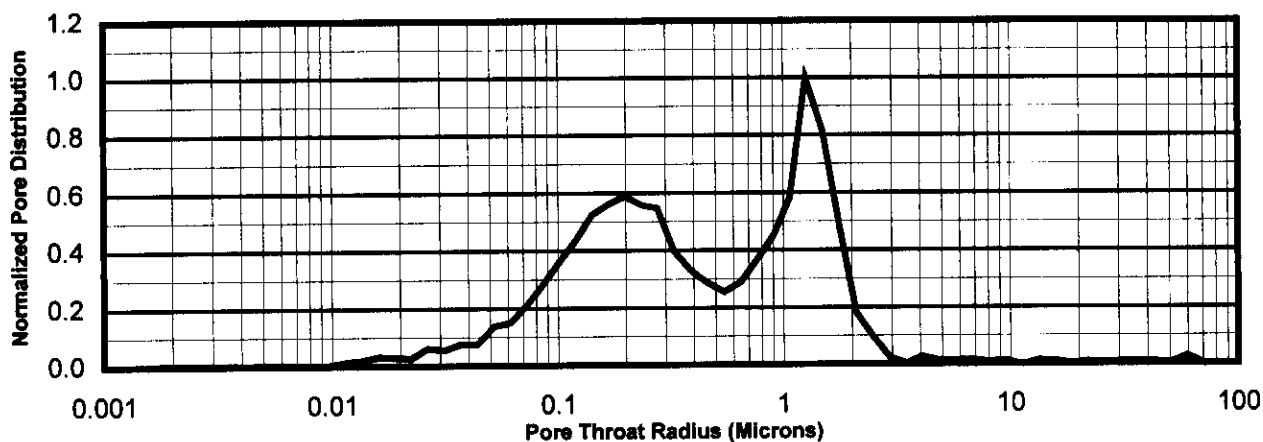
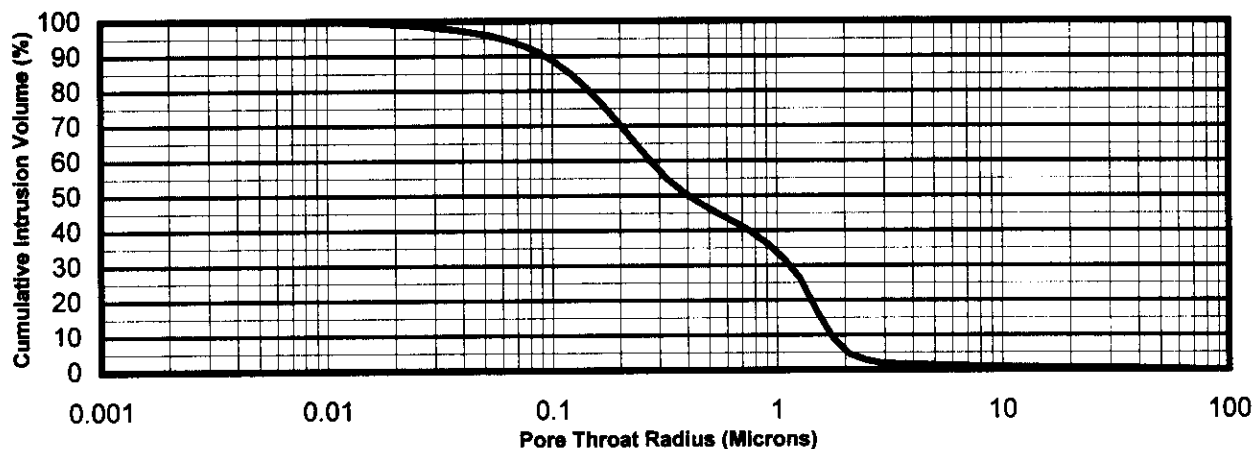


Company: Rigel Oil and Gas Ltd.  
Well: South Pipestone Prov. 06-09-006-26W1M  
Formation: TILSTON BEDS

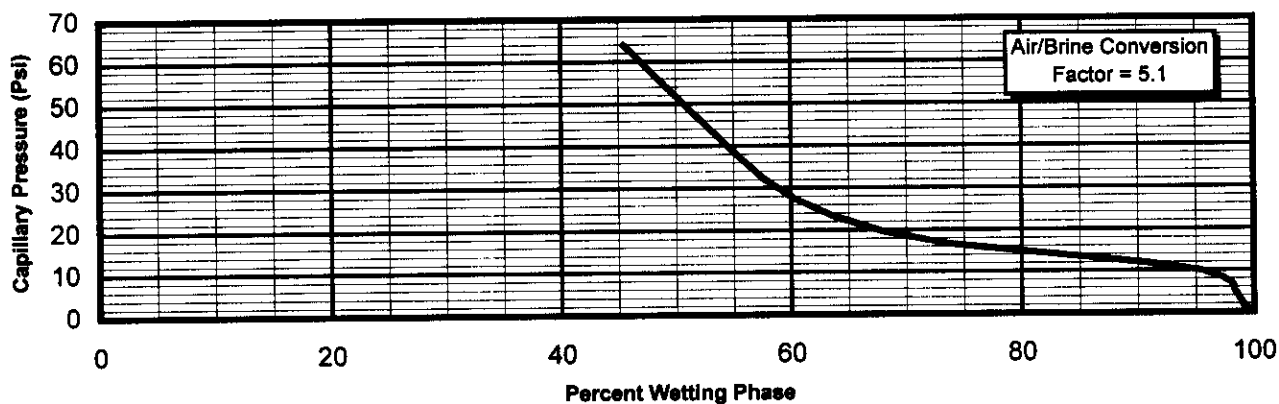
File: 98RE1587  
Date: 4/21/98

## FIGURE #3 MERCURY INJECTION STANDARD PLOTS

Sample: #1



### Mercury-Based Air/Brine Capillary Pressure Curve



Company: Rigel Oil and Gas Ltd.  
Well: Rigel South Pipestone Prov. 03-09-006-26W1M  
Formation: TILSTONE BEDS

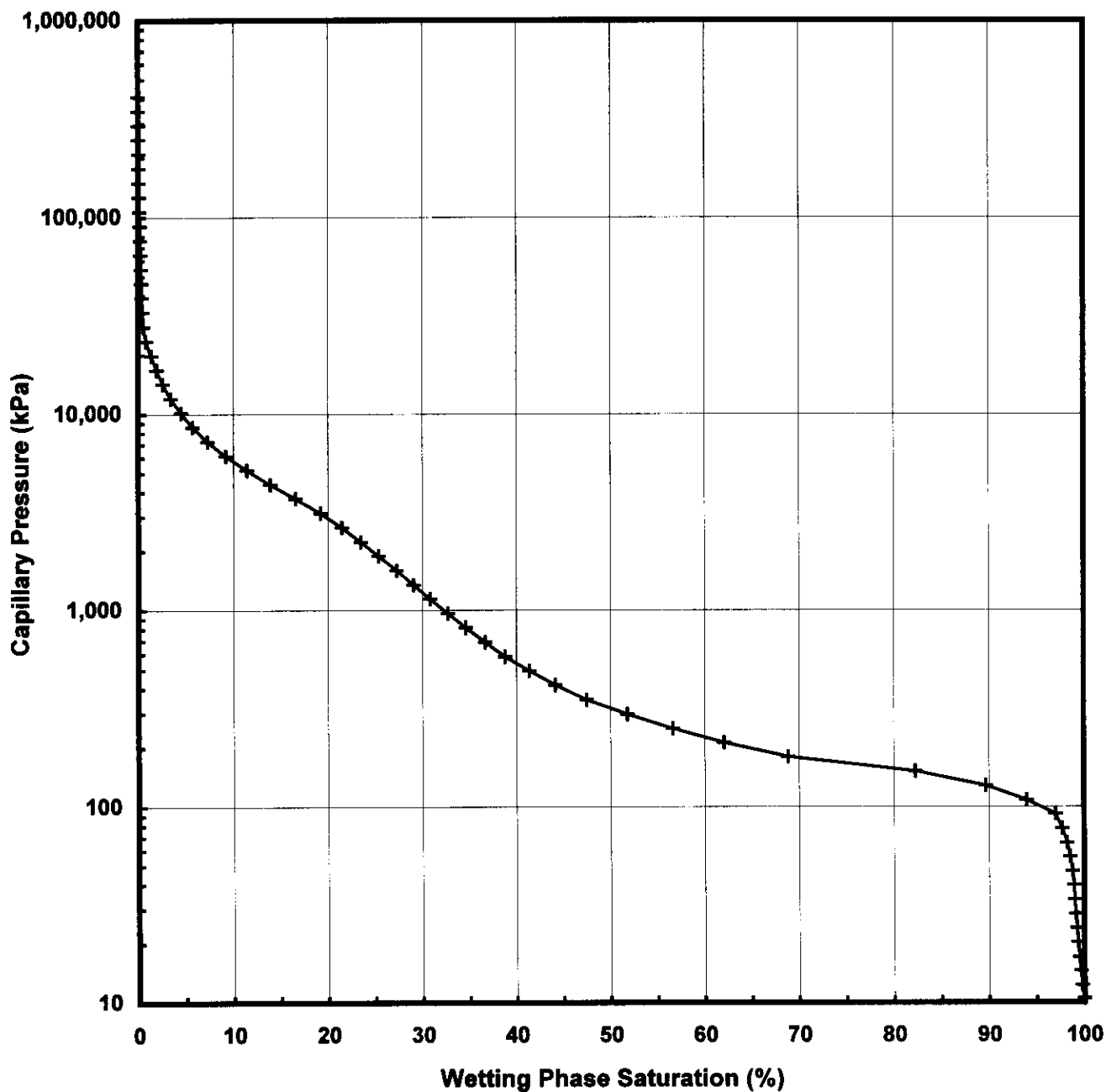
File: 98RE1587  
Date: 4/22/98

## FIGURE #6

### MERCURY INJECTION CAPILLARY PRESSURE

Sample: #3  
Depth: 772.18 m

Winland Perm: 22.951 md  
Hg Porosity: 12.90 %

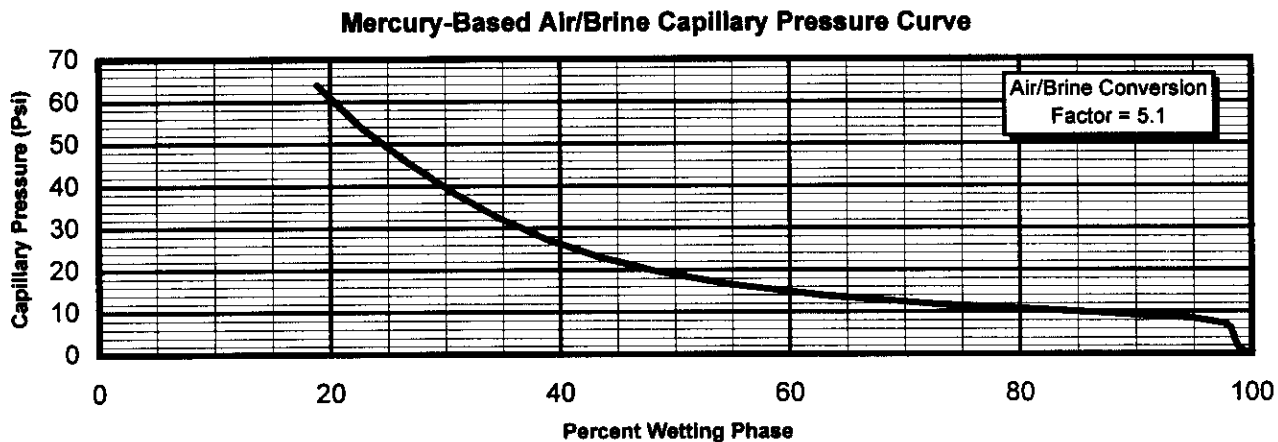
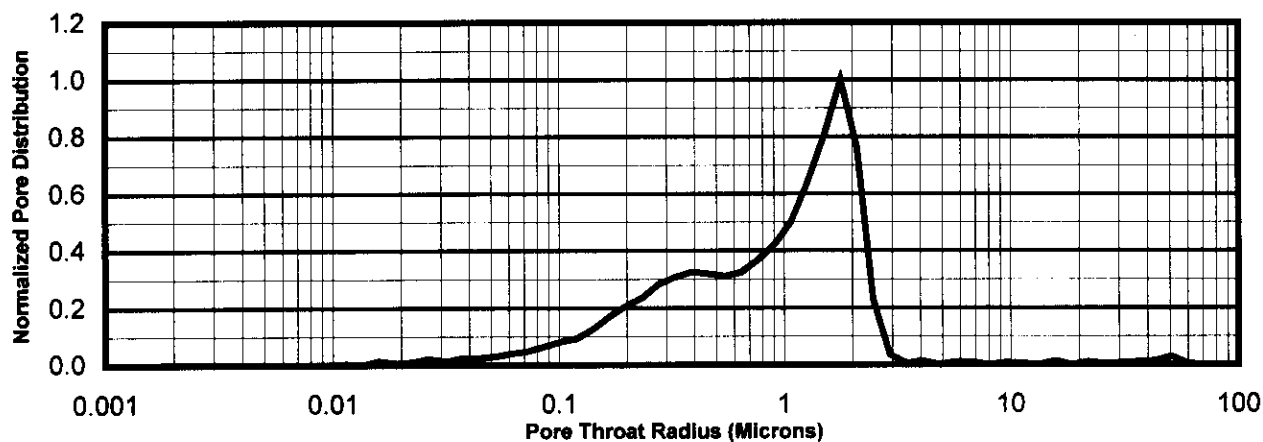
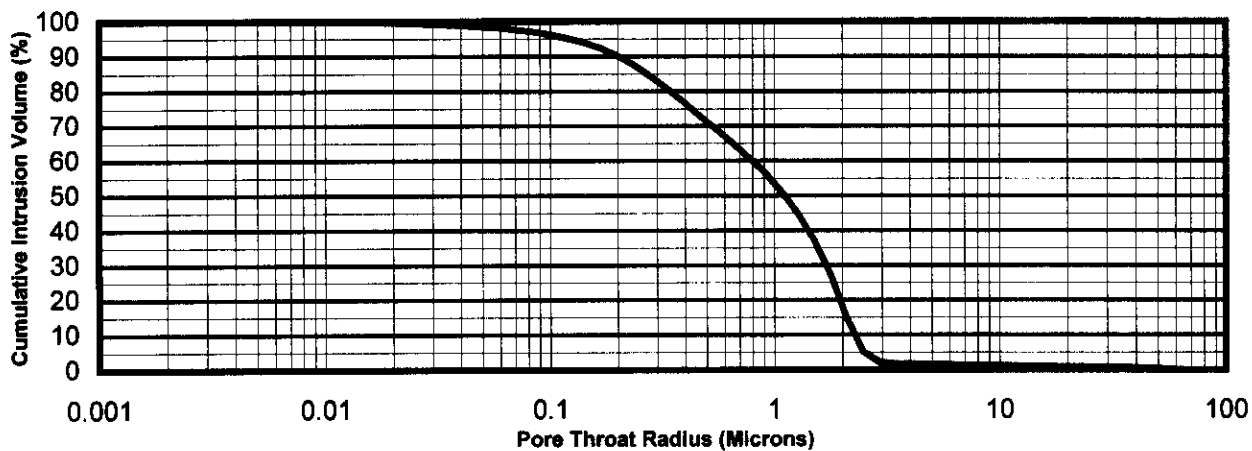


Company: Rigel Oil and Gas Ltd.  
Well: South Pipestone Prov. 06-09-006-26W1M  
Formation: TILSTON BEDS

File: 98RE1587  
Date: 4/21/98

## FIGURE #5 MERCURY INJECTION STANDARD PLOTS

Sample: #2



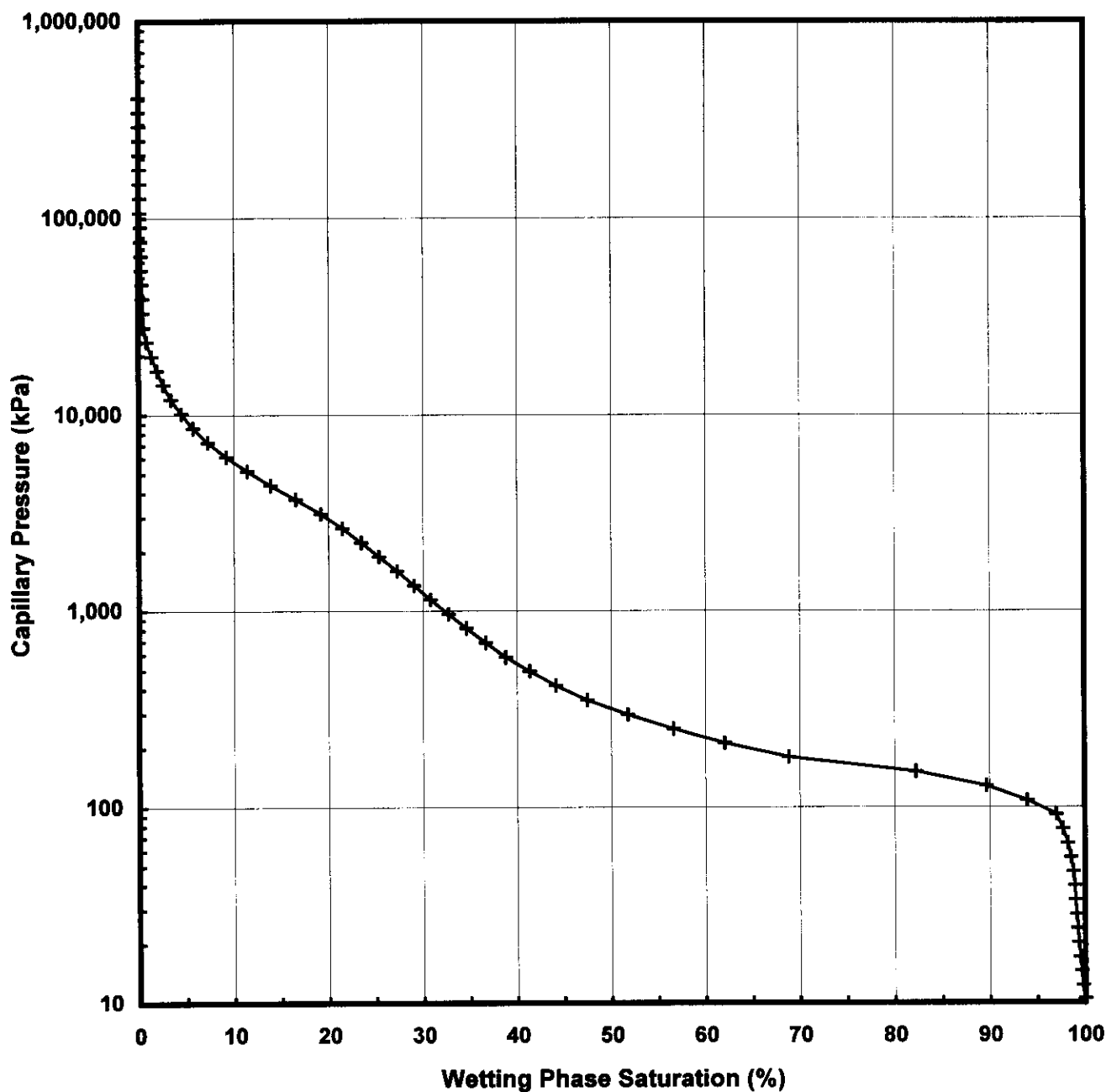
Company: Rigel Oil and Gas Ltd.  
Well: Rigel South Pipestone Prov. 03-09-006-26W1M  
Formation: TILSTONE BEDS

File: 98RE1587  
Date: 4/22/98

## FIGURE #6 MERCURY INJECTION CAPILLARY PRESSURE

Sample: #3  
Depth: 772.18 m

Winland Perm: 22.951 md  
Hg Porosity: 12.90 %

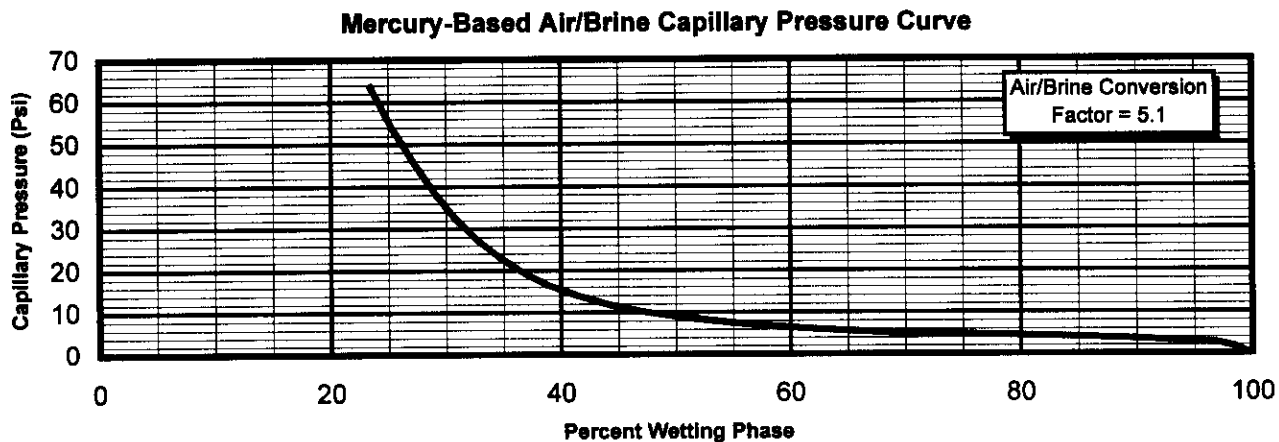
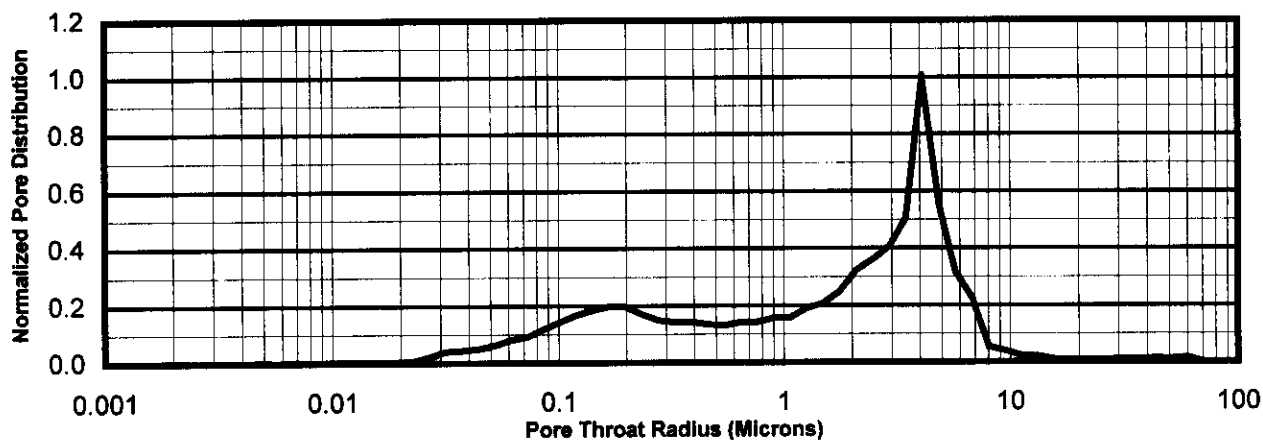
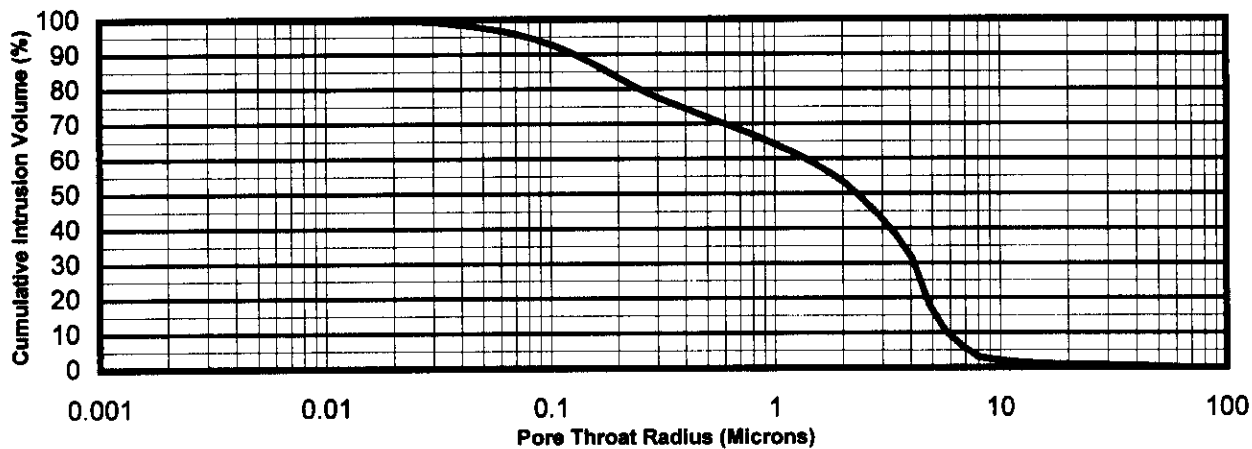


Company: Rigel Oil and Gas Ltd.  
Well: Rigel South Pipestone Prov. 03-09-006-26W1M  
Formation: TILSTONE BEDS

File: 98RE1587  
Date: 4/22/98

## FIGURE #7 MERCURY INJECTION STANDARD PLOTS

Sample: #3



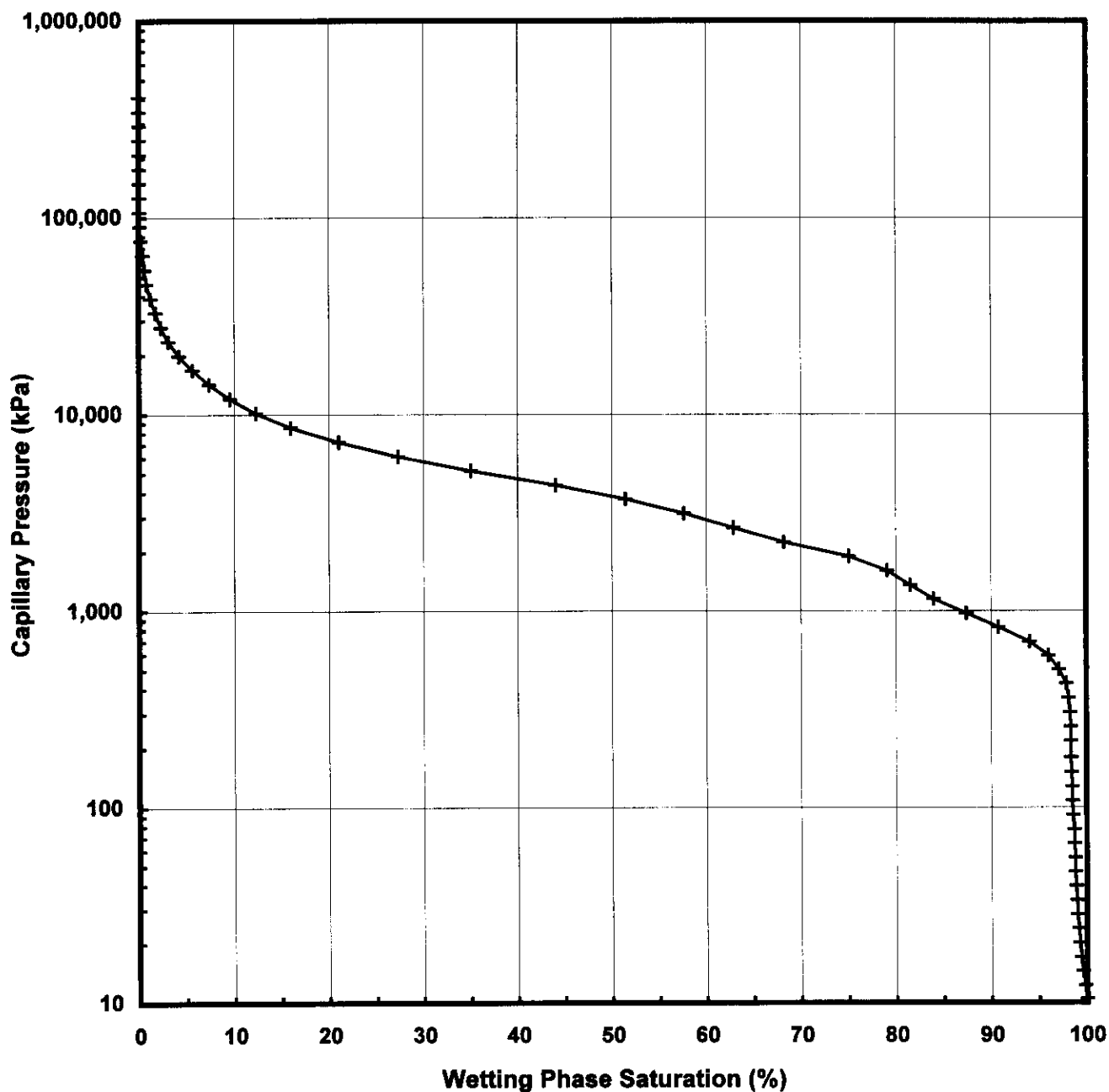
Company: Rigel Oil and Gas Ltd.  
Well: Rigel South Pipestone Prov. 03-09-006-26W1M  
Formation: TILSTONE BEDS

File: 98RE1587  
Date: 4/23/98

## FIGURE #8 MERCURY INJECTION CAPILLARY PRESSURE

Sample: #4  
Depth: 774.59 m

Winland Perm: 0.3118 md  
Hg Porosity: 12.90 %

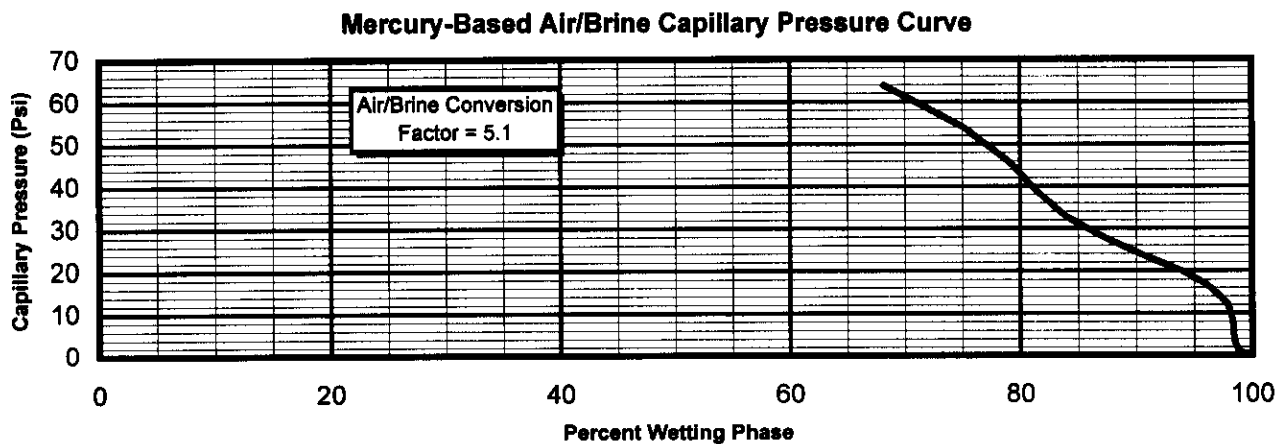
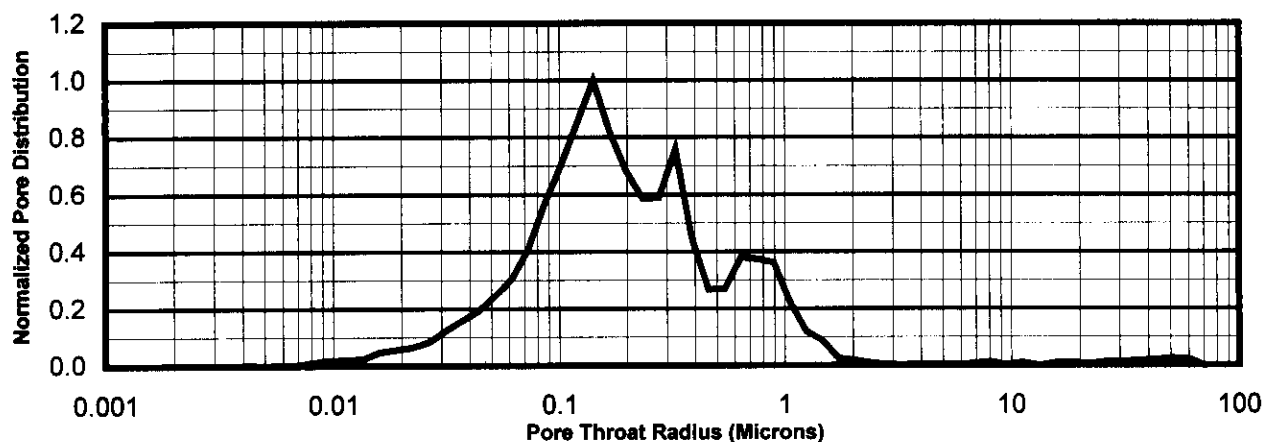
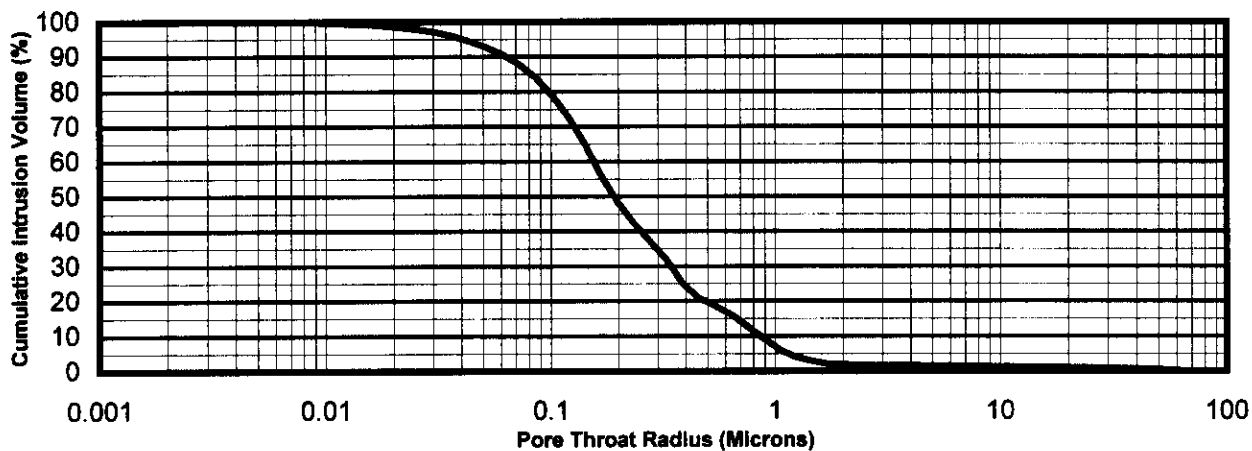


Company: Rigel Oil and Gas Ltd.  
Well: Rigel South Pipestone Prov. 03-09-006-26W1M  
Formation: TILSTONE BEDS

File: 98RE1587  
Date: 4/23/98

## FIGURE #9 MERCURY INJECTION STANDARD PLOTS

Sample: #4



Company: Rigel Oil and Gas Ltd.  
Well: Sceptre South Pipestone 07-16-006-26W1M  
Formation: TILSTONE BEDS

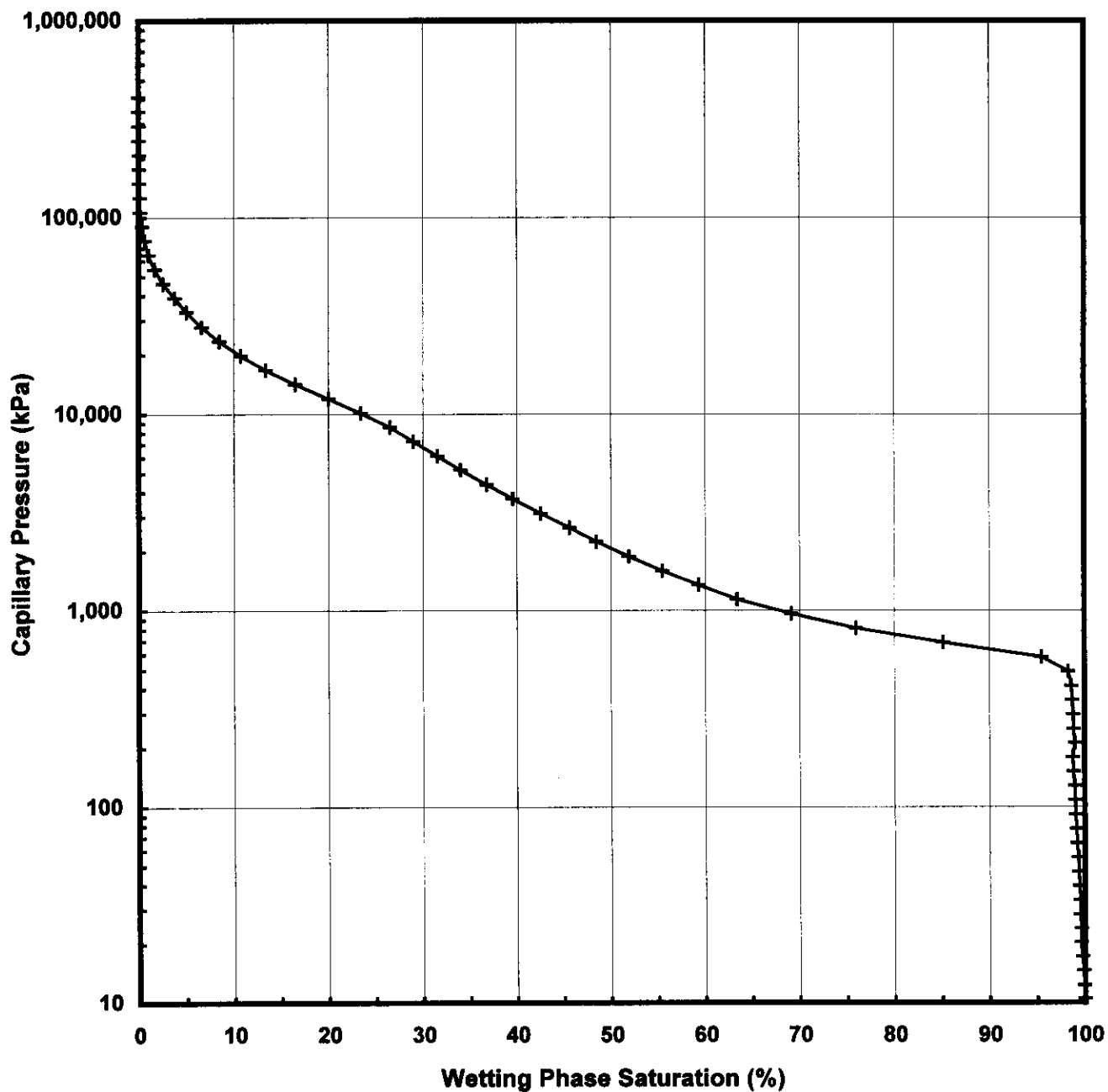
File: 98RE1587  
Date: 4/23/98

## FIGURE #10

### MERCURY INJECTION CAPILLARY PRESSURE

Sample: #5  
Depth: 754.7 m

Winland Perm: 1.2154 md  
Hg Porosity: 12.52 %

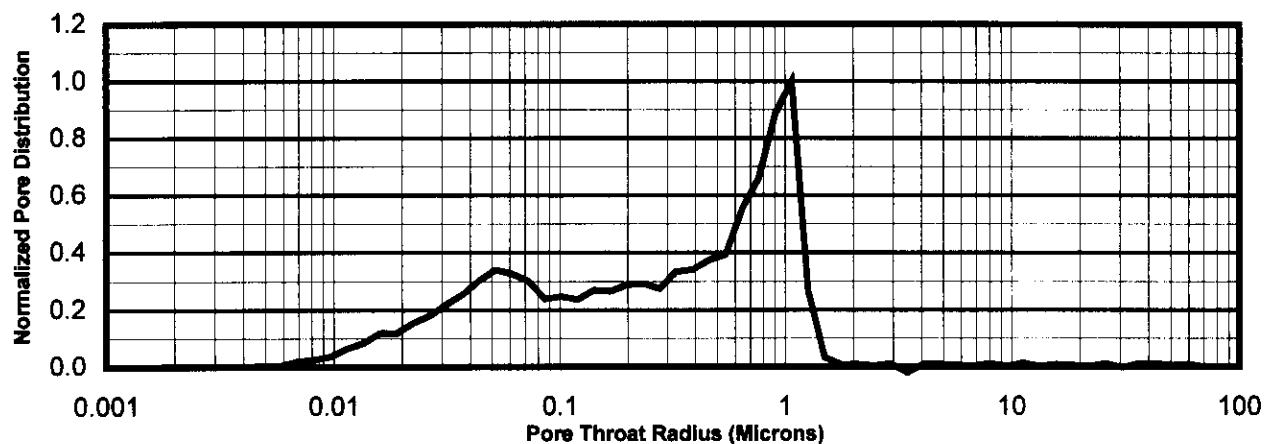
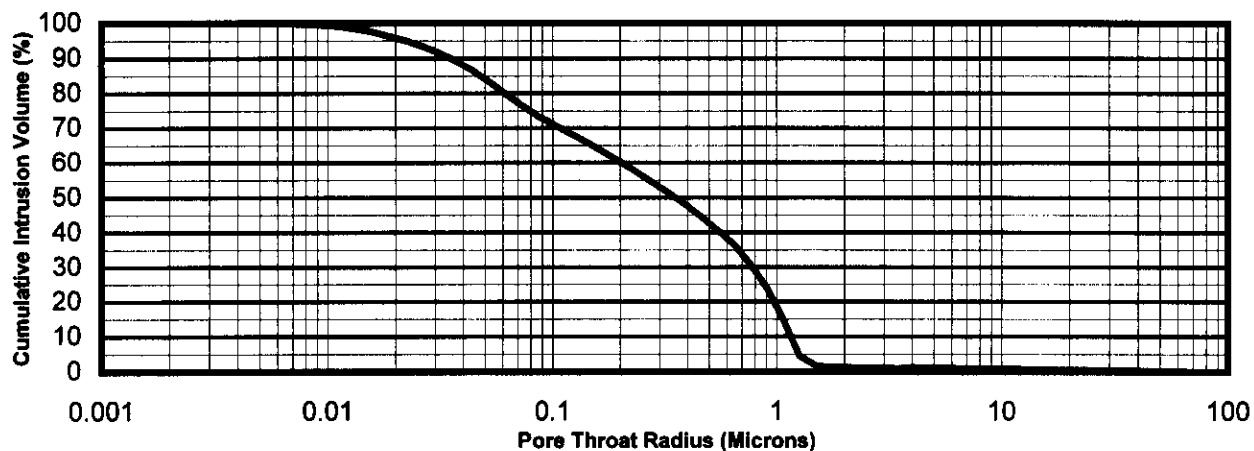


Company: Rigel Oil and Gas Ltd.  
Well: Sceptre South Pipestone 07-16-006-26W1M  
Formation: TILSTONE BEDS

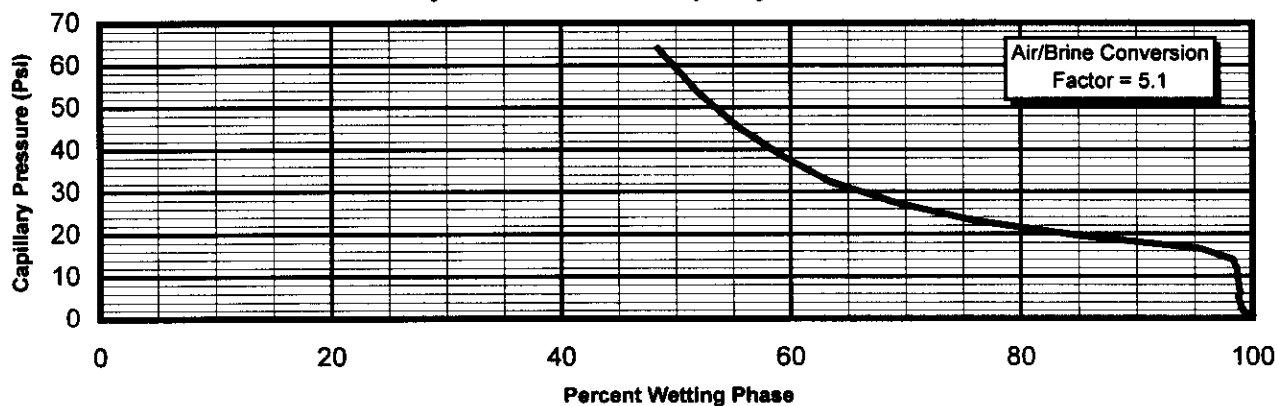
File: 98RE1587  
Date: 4/23/98

## FIGURE #11 MERCURY INJECTION STANDARD PLOTS

Sample: #5



### Mercury-Based Air/Brine Capillary Pressure Curve



Company: Rigel Oil and Gas Ltd.  
Well: Sceptre South Pipestone 07-16-006-26W1M  
Formation: TILSTONE BEDS

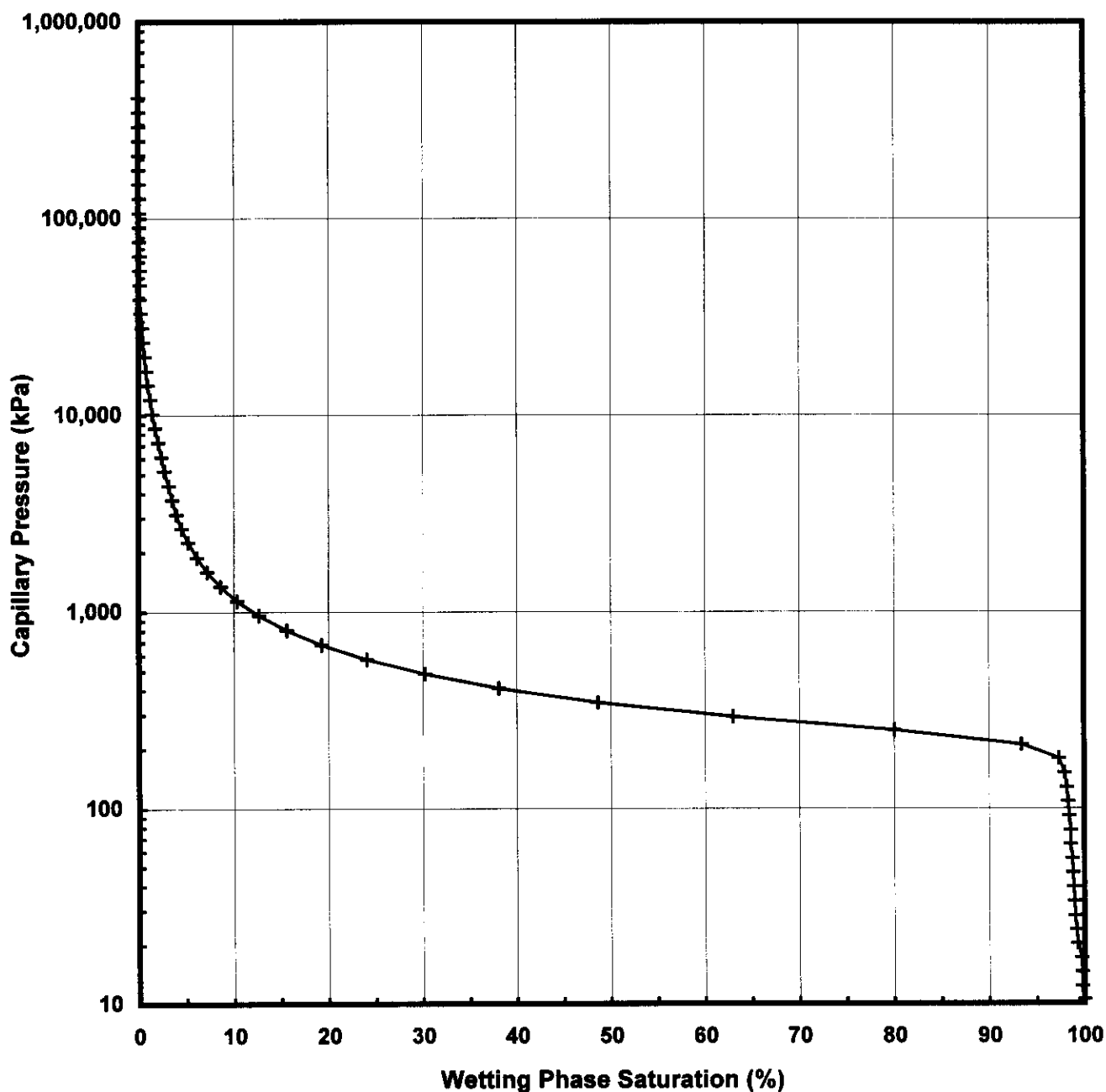
File: 98RE1587  
Date: 5/17/98

## FIGURE #12

### MERCURY INJECTION CAPILLARY PRESSURE

Sample: #6  
Depth: 757.6 m

Winland Perm: 33.188 md  
Hg Porosity: 25.64 %

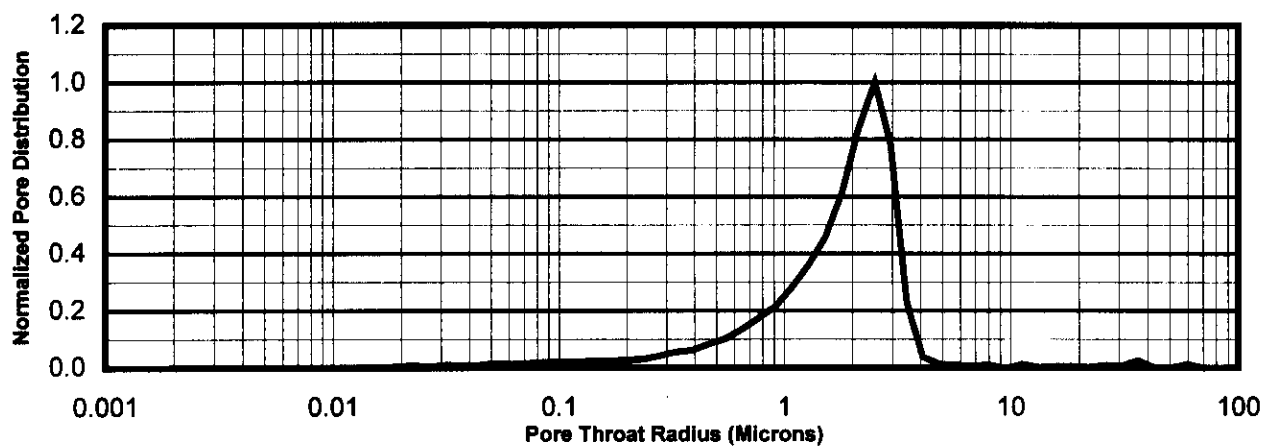
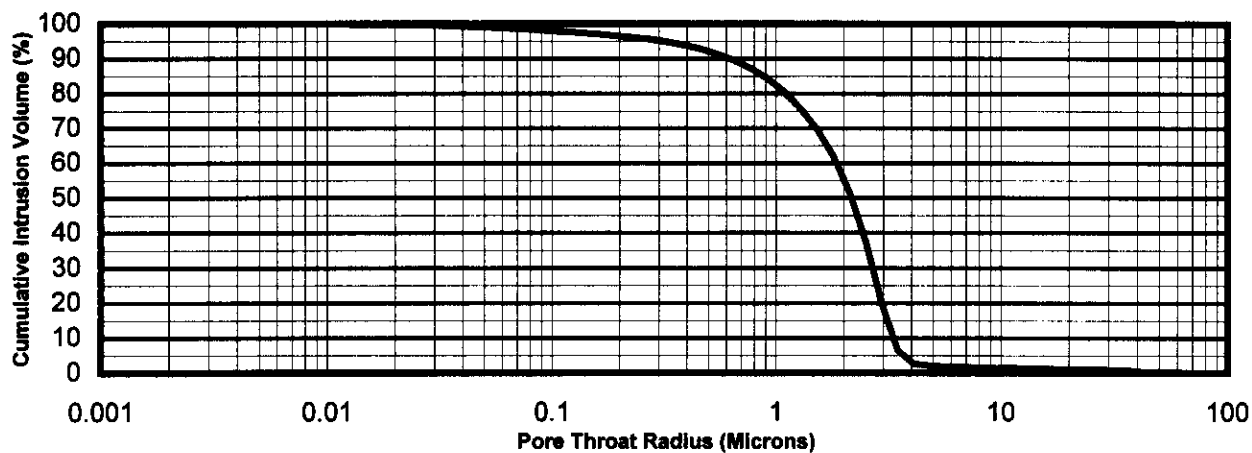


Company: Rigel Oil and Gas Ltd.  
Well: Sceptre South Pipestone 07-16-006-26W1M  
Formation: TILSTONE BEDS

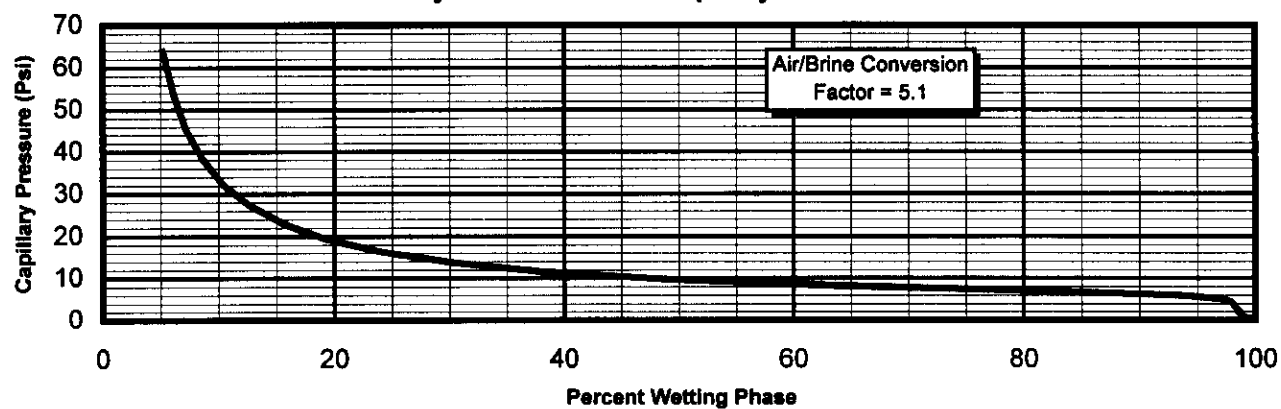
File: 98RE1587  
Date: 5/17/98

## FIGURE #13 MERCURY INJECTION STANDARD PLOTS

Sample: #6



### Mercury-Based Air/Brine Capillary Pressure Curve



Company: Rigel Oil and Gas Ltd.  
Well: Rigel South Pipestone Prov. 15-09-008-26W1M  
Formation: TILSTON BEDS

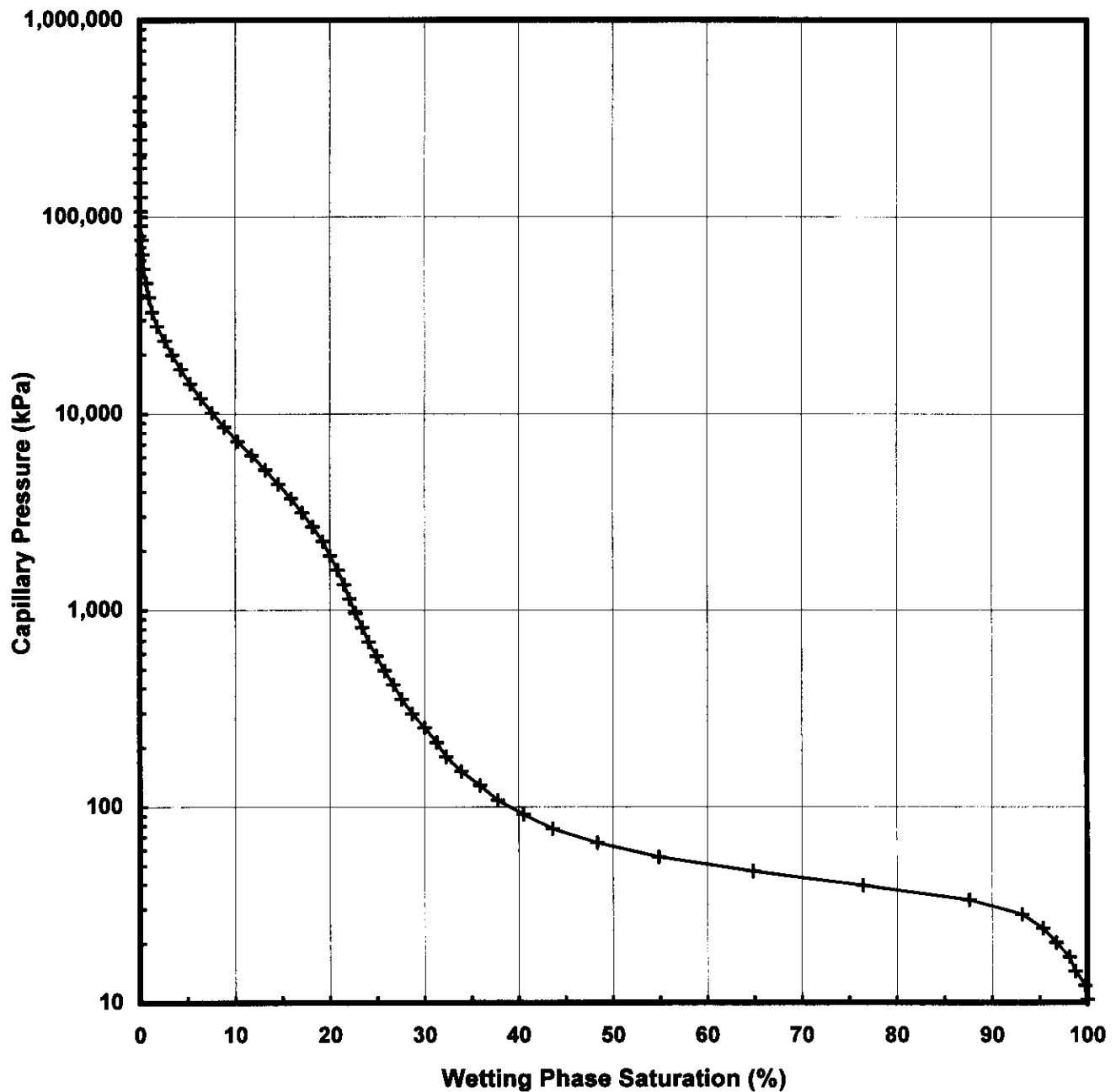
File: 98RE1587  
Date: 4/29/98

## FIGURE #14

### MERCURY INJECTION CAPILLARY PRESSURE

Sample: #7  
Depth: 759.06 m

Winland Perm: 431.65 md  
Hg Porosity: 17.96 %

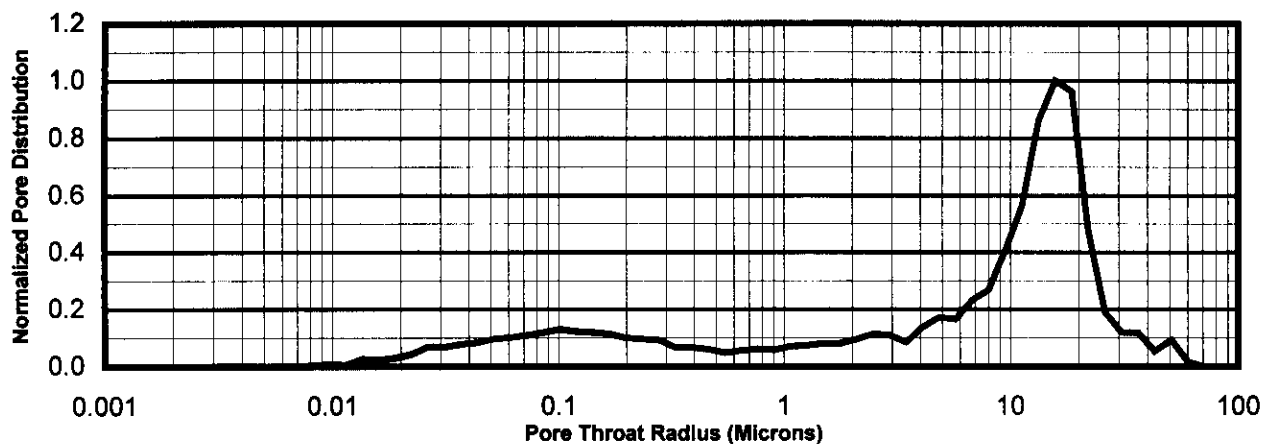
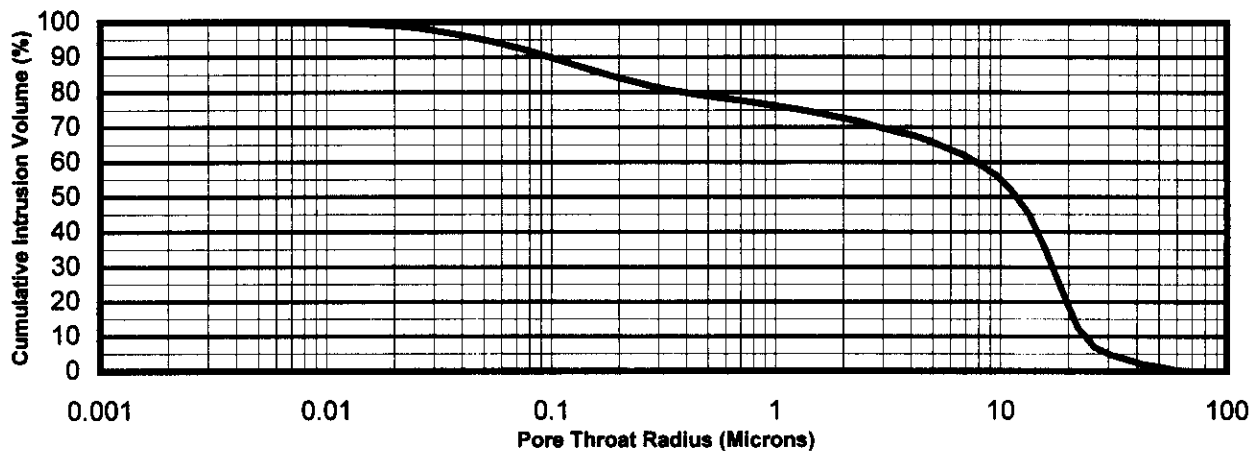


Company: Rigel Oil and Gas Ltd.  
Well: Rigel South Pipestone Prov. 15-09-006-26W1M  
Formation: TILSTON BEDS

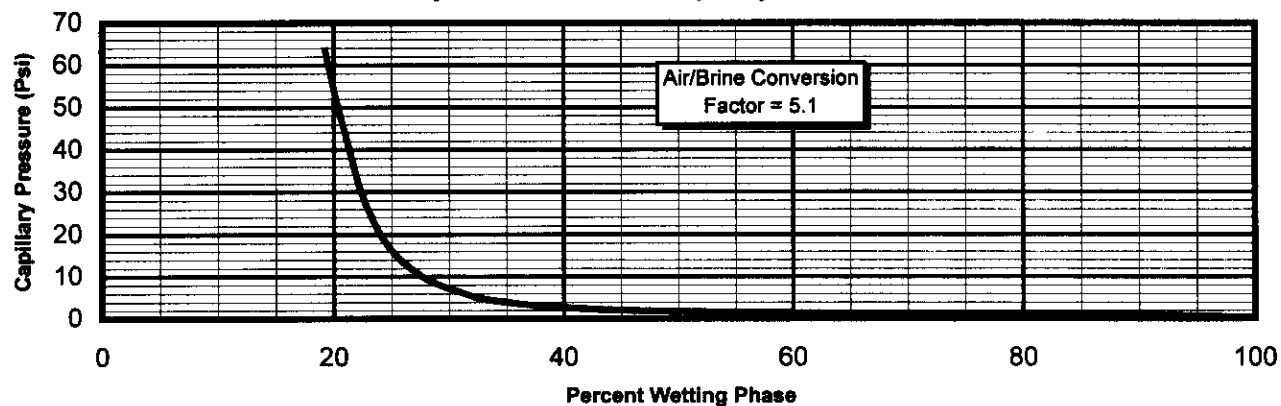
File: 98RE1587  
Date: 4/29/98

## FIGURE #15 MERCURY INJECTION STANDARD PLOTS

Sample: #7



### Mercury-Based Air/Brine Capillary Pressure Curve



Company: Rigel Oil and Gas Ltd.  
Well: Rigel South Pipestone Prov. 15-09-006-26W1M  
Formation: TILSTON BEDS

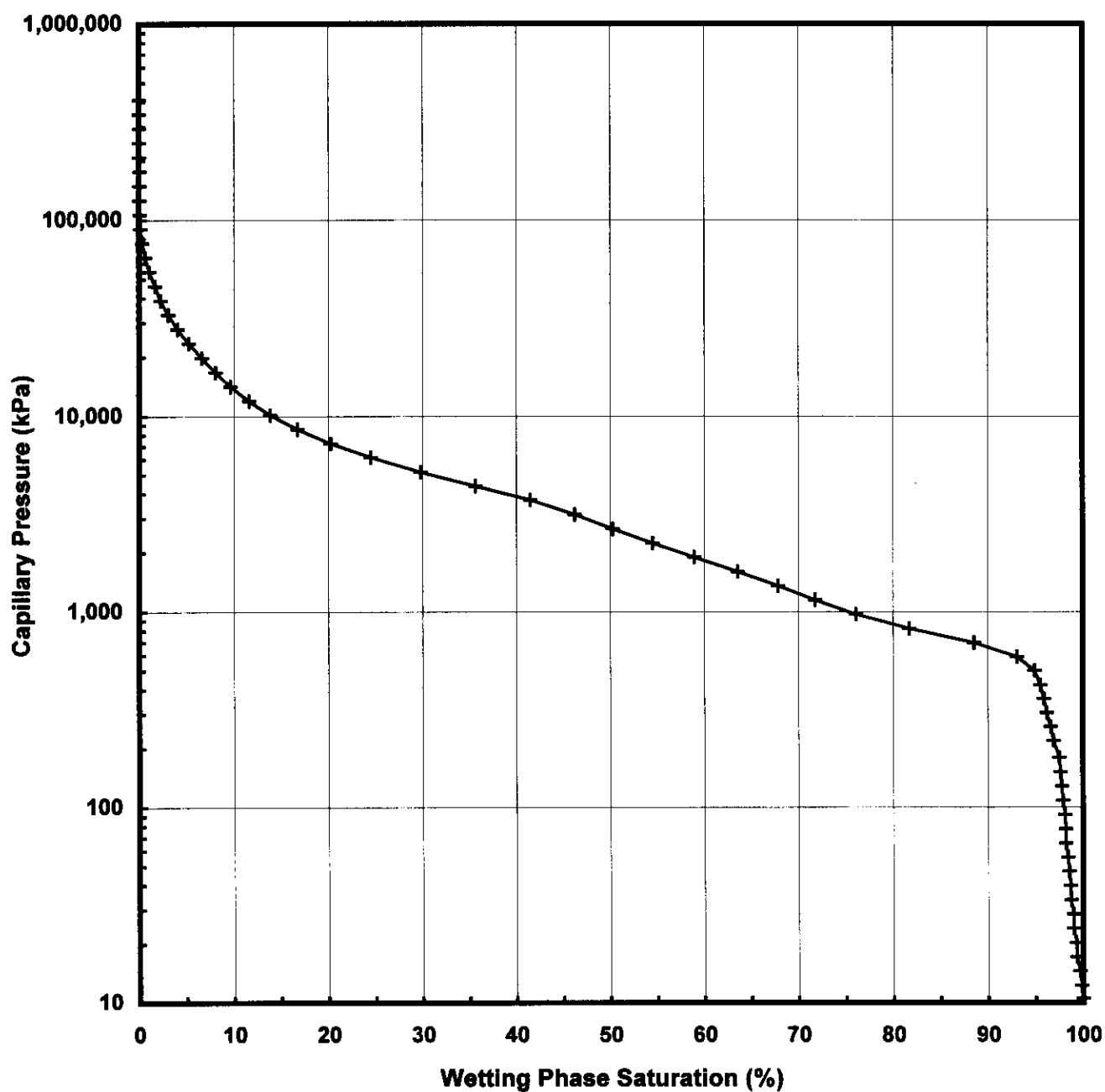
File: 98RE1587  
Date: 4/24/98

## FIGURE #16

### MERCURY INJECTION CAPILLARY PRESSURE

Sample: #8  
Depth: 761.18 m

Winland Perm: 0.9414 md  
Hg Porosity: 15.40 %

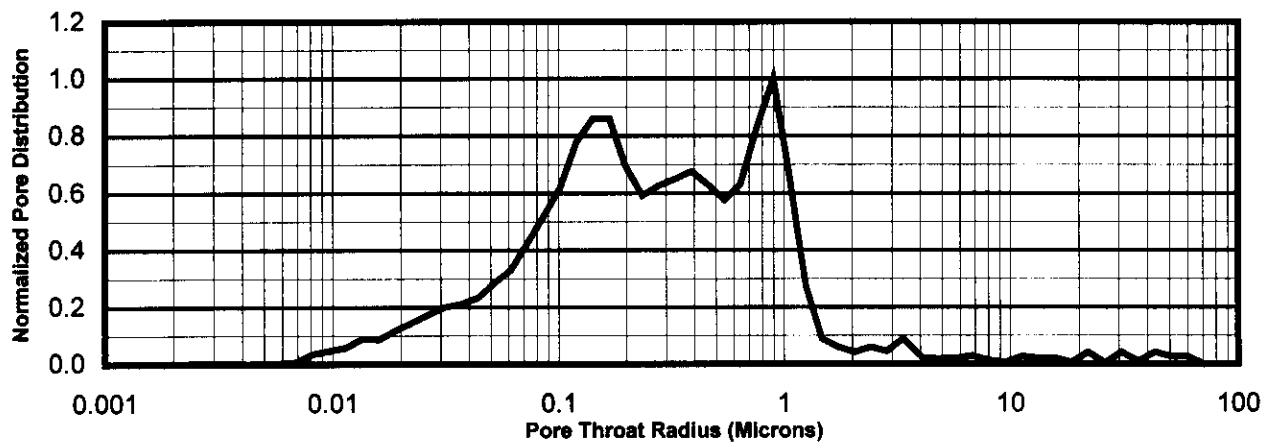
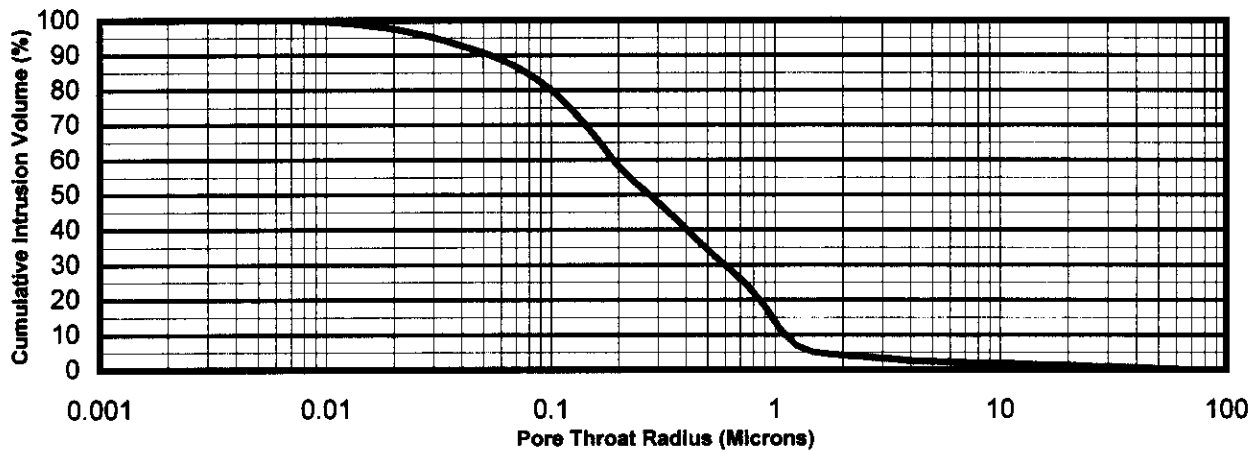


Company: Rigel Oil and Gas Ltd.  
Well: Rigel South Pipestone Prov. 15-09-006-26W1M  
Formation: TILSTON BEDS

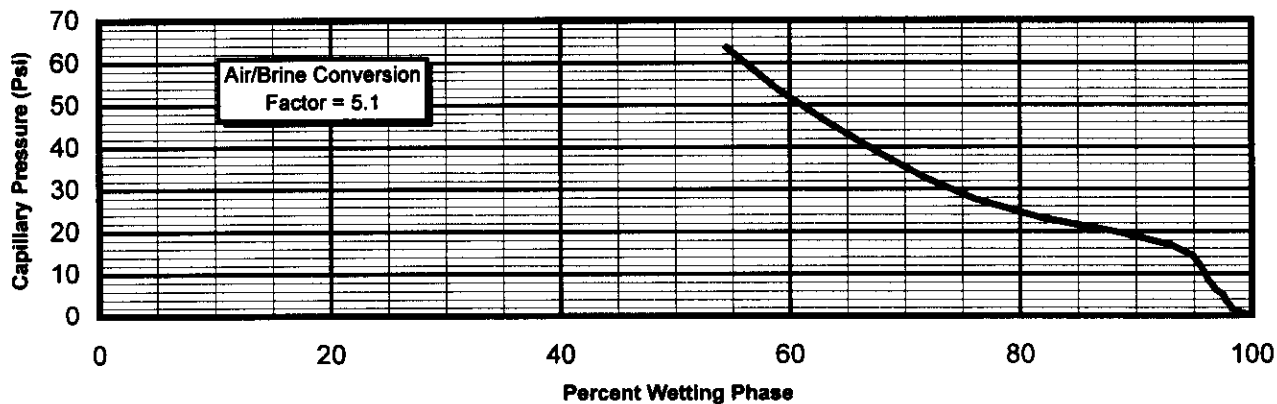
File: 98RE1587  
Date: 4/24/98


## FIGURE #17 MERCURY INJECTION STANDARD PLOTS

Sample: #8



### Mercury-Based Air/Brine Capillary Pressure Curve





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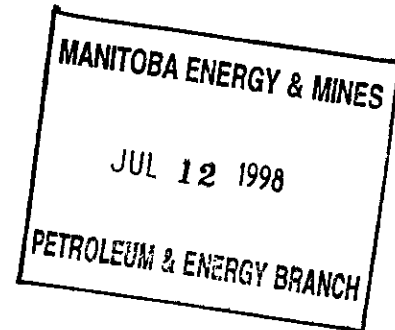
Prepared by Todd White MSc

**Rigel Oil & Gas Ltd.**

**Rigel\***

July 6, 1998

Carol D. Martiniuk  
Petroleum Geologist  
Manitoba Energy and Mines  
1395 Ellice Avenue  
Suite 360  
Winnipeg, Manitoba  
R3G 3P2



Dear Carol:

Please find enclosed a report of our Petrographic and Reservoir Quality Study in the Pipestone, Manitoba area. The bottom line seems to indicate potential formation damage, however, I must admit that the rocks do seem to be fairly tight. The second phase of the study is now underway, and includes work on drilling and completion fluids compatibility with the formation lithologies. I will send you a copy of that report when it is completed.

We are still working on our land position in Township 4, but hope to be drilling within a couple of months. I hope you have a great summer!

Sincerely,

**RIGEL OIL & GAS LTD.**

A handwritten signature in black ink, appearing to read "Brad Barrie".

Brad Barrie  
Senior Geologist

BB/dd  
Enclosure