Petroleum Open File Report POF 2-84

Geology and Hydrocarbon Potential of the Jurassic-Cretaceous in Southwestern Manitoba

By Wes Morningstar

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I. Introduction

Rocks of Jurassic age occur in southwestern Manitoba and represent deposits on the northern flank of the Williston Basin. These Jurassic sediments are a continuation of deposits to the southwest in Wyoming, Montana, North and South Dakota and to the west in the southern parts of Saskatchewan and Alberta (Stott 1955). Some 366 metres of Jurassic sediments are present in the deepest portions of the Williston Basin but these sediments thin to slightly less than 60 metres in some areas of southwestern Manitoba. This thinning is due to a general northward truncation by pre-Cretaceous erosion combined with a regional depositonal thinning toward the eastern margin of the Williston Basin (Milner and Blakslee 1956) (Figure 1).

A Jurassic oil discovery in 1983 by Troy Oils, Ltd., (Troy St. Lazare 1-21-16-29W1) resulted in the recovery of 18^{o} API oil. This discovery has lead to renewed interest in the Jurassic-Cretaceous sediments of southwestern Manitoba and southeastern Saskatchewan (Figure 3).

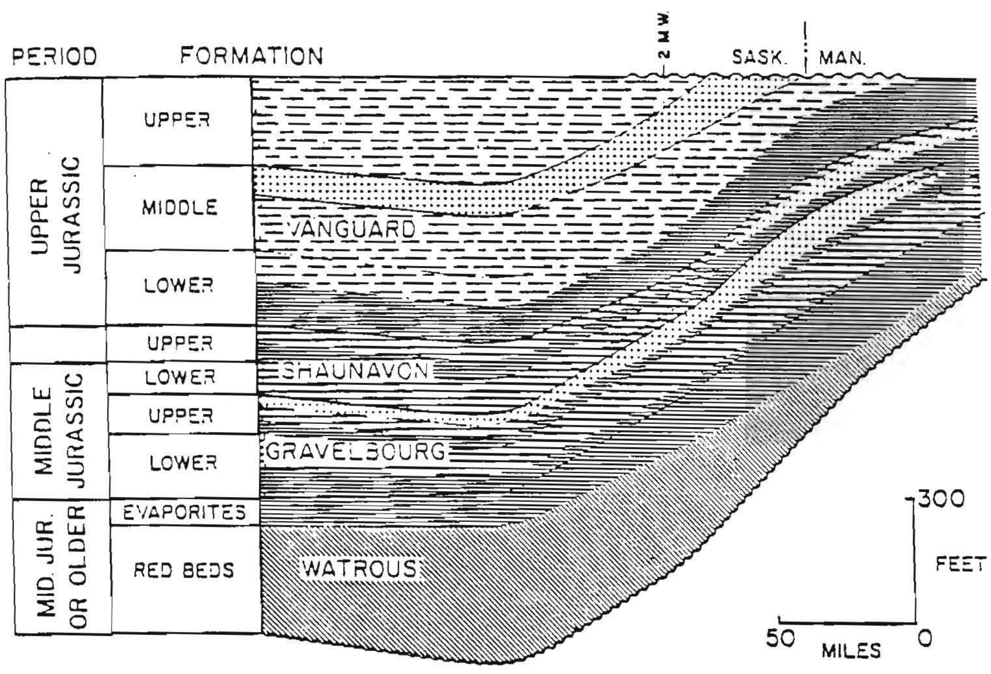

Figure 1. Schematic section through Jurassic basin in Saskatchewan along the International Boundary-east half. (from Klingspor, 1958)

A. Study Area

This report focuses on 28 townships in southwestern Manitoba extending from Township 12, Ranges 26-29 WPM in the south to Township 18 Ranges 26-29 WPM in the north (Figure 2). A regional study of the area has been undertaken in order to highlight areas which may be prospective for future detailed evaluation.

B. Purpose of Study

The purpose of this report is to discuss and determine the potential for oil entrapment in Jurassic-Cretaceous sediments. Few studies have been undertaken in the Jurassic-Cretaceous since Milner and Thomas (1954), Stott (1955)and Klingspor (1958) published their reports.

A number of stratigraphic and structural cross-sections, structure contour maps and isopach maps have been constructed throughout the study area. Each has been designed for a specific purpose and will be discussed at length later in the report. Electrical logs were used to pick formation tops and for correlation purposes due to the fact that in most of the older wells studied, electrical log surveys

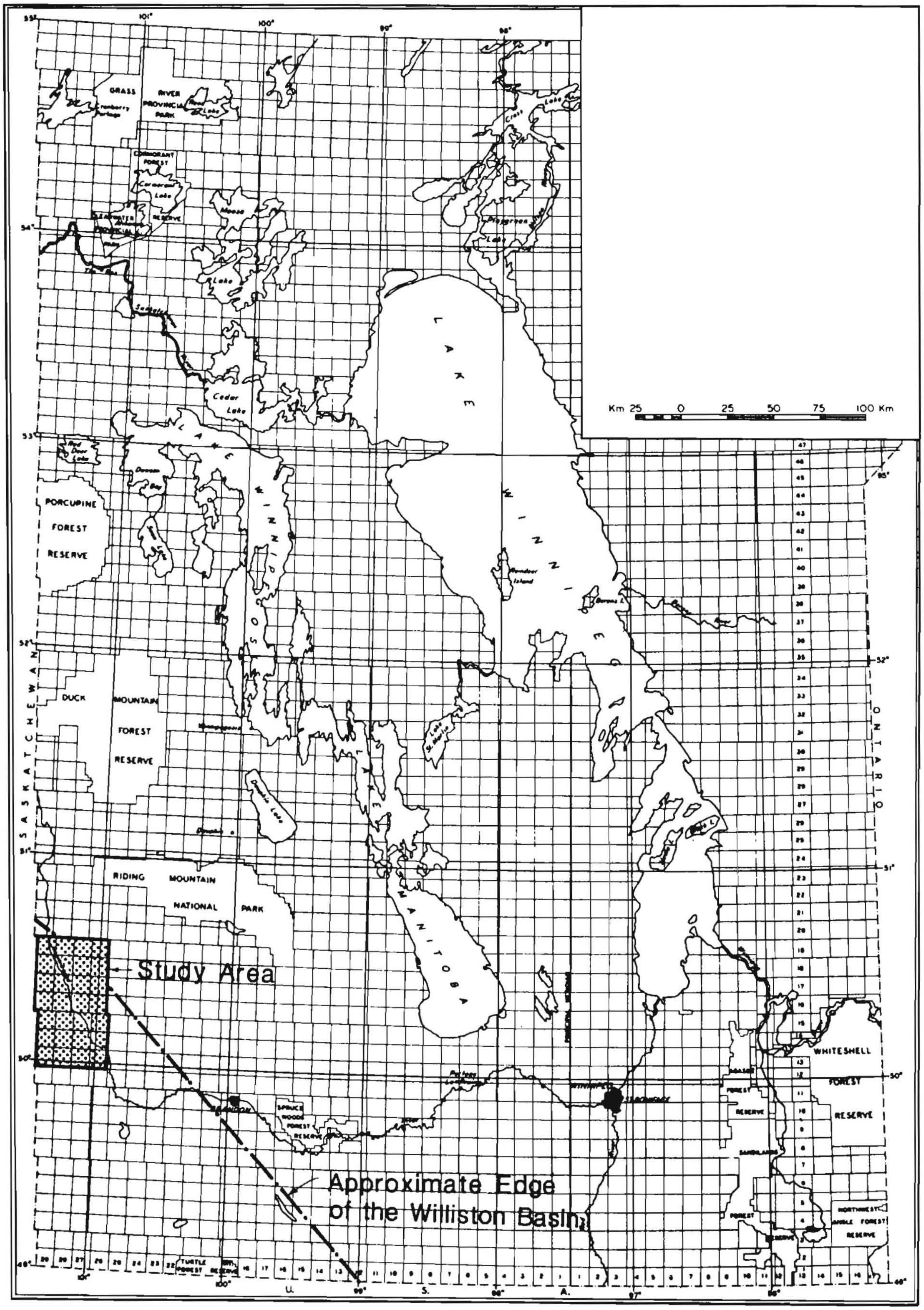

Figure 2. Regional map of Manitoba Illustrating Study Area.

were the only form of geophysical well-logging available. Core samples and cuttings were used for lithologic interpretations. A lack of core exists due to the difficulty of coring and recovering the rather poorly consolidated Jurassic and Cretaceous sediments, but all available core which could be utilized in the study was examined. Cuttings were also described for many wells but the overall sample quality is questionable. Complete core and sample descriptions are found in Appendix I. The problems that exist in defining oil entrapment within the study area are numerous and varied:

1. The Jurassic-Cretaceous sediments are difficult to differentiate and difficulty has arisen in trying to determine the Jurassic-Cretaceous contact due to depositional thinning of the Jurassic and erosional truncation of the Jurassic sediments by pre-Cretaceous erosion.

2. Poor well control and overall poor logging techniques have resulted in a limited data base.

3. The lack of good correlatable markers in the northern portion of the study area is a result of the rapidly changing facies.

4. A lack of core samples or good quality cuttings limits lithologic description and interpretation.

5. An area of only 28 square townships has been studied. This factor makes it difficult to derive a geologic and depositional history of the study area when the entire regional stratigraphy of southwestern Manitoba has not been fully studied by the author.

C. Stratigraphic Nomenclature

In Manitoba, no satisfactory stratigraphic subdivision for the Jurassic overlying the lowermost Watrous has yet been established, other than several preliminary attempts by Francis (1956), Milner and Thomas (1954), Peterson (1957) and Stott (1955). A direct attempt to establish a stratigraphic subdivision for the Jurassic has been avoided in this study due to the lack of core, samples and other lithologic evidence required for such an interpretation. For the purposes of this report Milner and Thomas's (1954) stratigraphic nomenclature for Saskatchewan will be implemented.

The undifferentiated nature of the Jurassic stratigraphy in southeastern Saskatchewan and southwestern Manitoba is due to a loss of distinguishing characteristics as a result of thinning and interfingering of sediments (Stott 1955). In southwestern Manitoba it is believed that only parts of the Vanguard and Shaunavon Formations exist, yet these two formations are also difficult to differentiate from one another based on the small amount of lithologic evidence currently available (Figure 3).

While Stott may be correct in saying that a loss of distinguishing characteristics occurs, it is believed that Saskatchewan terminology, at least in part, can be applied to the Jurassic stratigraphy of Manitoba. Inasmuch as the formation names are carried across facies boundaries, the requirements for stratigraphic nomenclature are not fully met. However, it is felt that with the fragmentary knowledge we have of the Jurassic beds of southeastern Saskatchewan and southwestern Manitoba it is best to adhere to the most simple and widely recognized classification (Table 1).

II. Stratigraphy and Structure

R.L. Milner and G.E. Thomas (1954) divided the Jurassic in Saskatchewan into four lithologic units which in ascending order are named the Watrous, Gravelbourg, Shaunavon and Vanguard. Only in the southwestern and central parts of Saskatchewan are the four formations fully recognized. In the southeastern portions of Saskatchewan and southwestern portions of Manitoba the Jurassic sequence thins as the Paleozoic erosional surface rises.

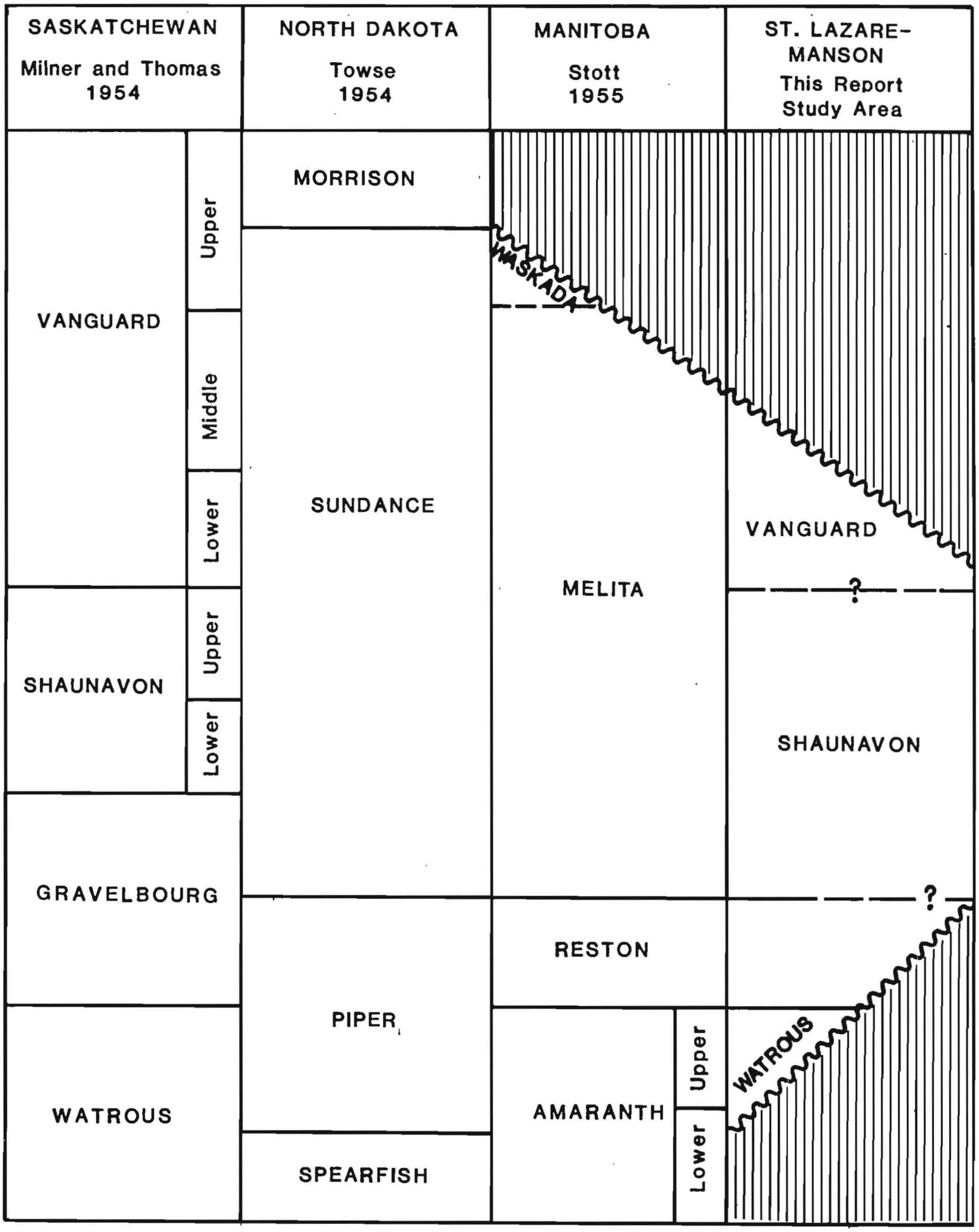

Table 1: Jurassic Stratigraphic Correlation Chart.

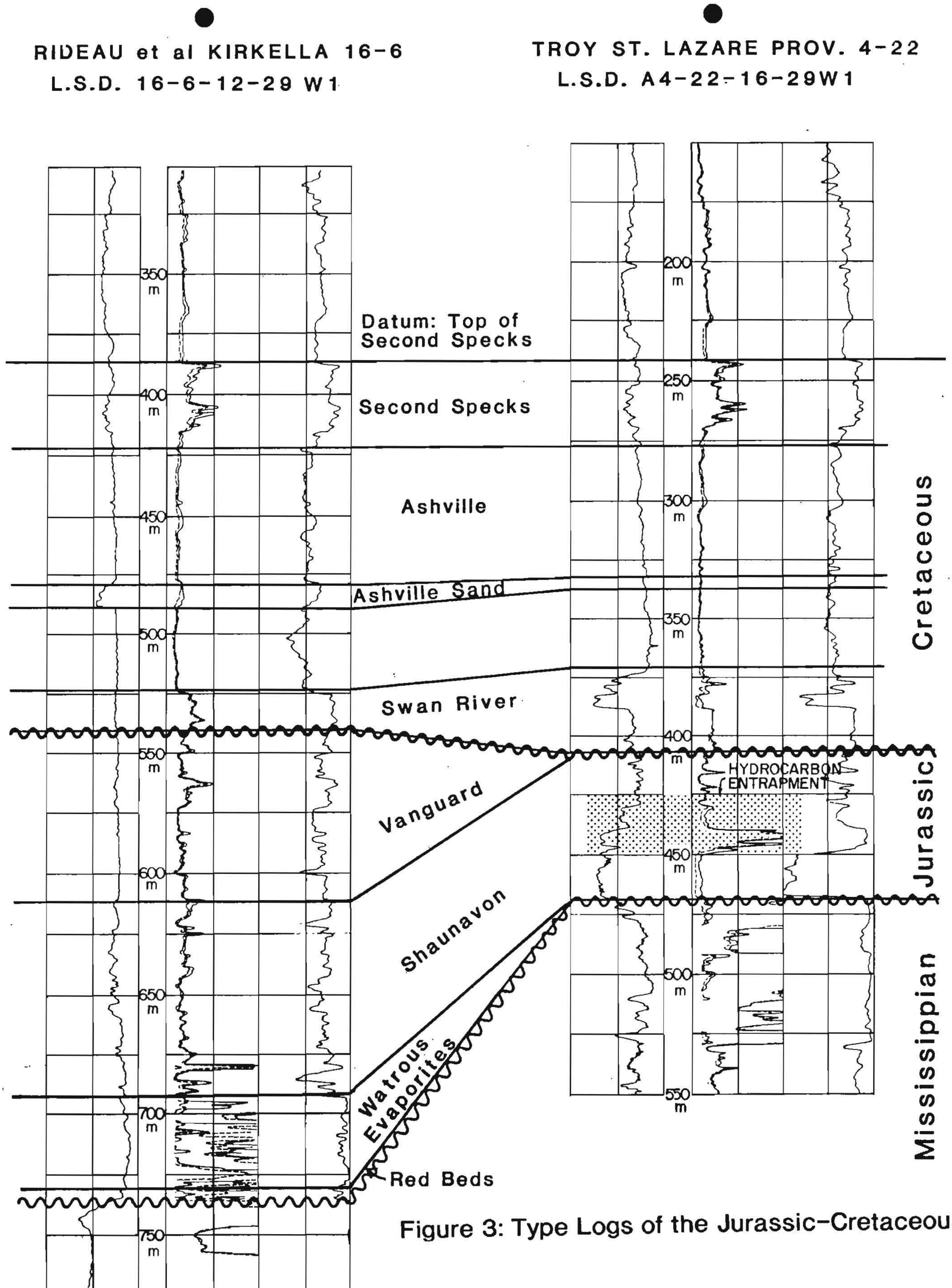

Figure 3: Type Logs of the Jurassic-Cretaceous

A number of stratigraphic cross-sections were constructed throughout the study area in order to achieve familiarity with correlations.

Figure 4 shows the location of the two representative stratigraphic cross-sections which have been included in this report. (Figures 5 and 6). The top of the Second Specks Formation has been used as a datum since no satisfactory marker exists deeper in the section.

Data from over 200 electrical well logs have been used to construct structure contour maps, isopach maps and sand/shale ratio maps over the study area. The stratigraphy and structure for each of the units examined in the study area will be discussed in the following sections.

A. Mississippian

A period of extensive erosion of the Paleozoic surface occurred prior to the deposition of the basal Mesozoic (Jurassic) red beds. On a regional scale the Mississippian (Lodgepole) erosional surface appears to be relatively uniform in the study area (Map 1), but more detailed maps show it to be quite irregular. The irregular nature of the Mississippian erosional surface influenced Watrous deposition but is believed to only have minimally influenced the remainder of Jurassic deposition. The subcropping carbonate strata, which consist mainly of limestones and dolomitic limestones, dip gently southwestward into the Williston Basin. The erosional edge of the Lodgepole occurs in the northeastern portion of the study area, as shown by the structure contour map of the Lodgepole Formation.

B. Jurassic

The sequence and thickness of Jurassic sediments is greater and more well defined in the southern parts of the study area, however, contacts between the Watrous, Shaunavon and Vanguard formations of the Jurassic are not easily identifiable. The lowermost formation of post-Mississippian age in Manitoba is the Watrous Formation and it is the most easily identified in the Jurassic stratigraphic sequence. The lower Watrous consists of a basal red siltstone with some red shale and sandstone; it is overlain by the upper Watrous, a sequence of anhydrites which is interbedded with minor amounts of shale. The red beds, or lower Watrous, fill lows on the eroded surface of the Mississippian, reducing the relief on this surface to a point where it had little effect on the marine sedimentation of the later Jurassic sediments. The evaporites of the upper Watrous were formed in a restricted marine environment in which brine concentrations were maintained over a long period of time, thus allowing huge thicknesses of evaporites to develop.

The Watrous formation is most easily recognized in the southern portions of the study area. However, north of Township 12 both the lower and upper Watrous appear to pinch out against the Paleozoic erosional surface. Transgressing seas deposited the silty-shaly material which overlies the evaporites and erosional surface to the north. The top of this silty-shaly sequence can be identified on electrical logs on the basis of a spike on the resistivity curve (Figure 3). In the past this resistivity marker was referred to as the 'Jurassic lime marker' and density-neutron crossplots indicate that it may be a limestone. However, lithologic evidence to support the crossplot data does not exist in the study area. Where the watrous does not occur this unit immediately overlies the Paleozoic erosional surface. This silty-shaly sequence is, in turn, overlain by sandstones which are interbedded with shales to varying degrees. The cleaner more well developed sandstones appear to be found further up dip in a northward direction in the study area.

The writer believes that the Gravelbourg Formation is absent in the map area and that the Shaunavon Formation immediately overlies the Watrous in the southern part of the study area and the Paleozoic erosional surface in the northern part. The absence of the Gravelbourg is probably due to non-deposition or facies changes as no evidence exists to suggest the presence of an unconformity prior to Shaunavon deposition. The Shaunavon consists mainly of an interbedded sandy-shaly sequence. The sand unit appears to become progressively more well developed to the north but shaly interbeds are still present. In the northern portion of the map area well developed Shaunavon sandstones may immediately overlie the Mississippian unconformity. In the areas where this occurs, migration of oil from Paleozoic reservoirs could result in oil accumulations in the Jurassic sediments.

Although stratigraphic subdivision of the Jurassic is difficult throughout the study area a distinction between the Shaunavon and overlying Vanguard is possible throughout most of the map area. A marker defined as the 'L' marker on the resistivity curve (Figure 6) has been identified as the base of the Vanguard and the top of the Shaunavon Formation. This contact is based on tentative regional correlations which appear to coincide with correlations in Saskatchewan. The Vanguard is the uppermost formation of the Jurassic present in the study area and only a portion is present as the uppermost beds have been removed by pre-Cretaceous erosion. In cases where the Vanguard shale is well defined the Jurassic-Cretaceous boundary appears to be identifiable. Where the Vanguard Shale is absent, difficulty arises in trying to distinguish the Jurassic-Cretaceous contact due to the similarities of the sediments in terms of their log responses and the overall lack of lithologic data.

A total Jurassic isopach map has been constructed to illustrate the depositional and erosional thinning and thickening of the Jurassic (Map 2). However, due to the difficulty in attempting to define the top of the Jurassic some doubt may be cast on this particular map. The difficulty arises due to pre-Cretaceous erosion and subsequent deposition of sandstones similar in log character to those deposited in the Jurassic. A general thinning of the Jurassic occurs to the north which may be a function of pre-Cretaceous erosion, or deposition of the sediments onto the flank of the basin. In the eastern portions of the map area a sudden thickening of the Jurassic occurs which is very pronounced.

The sand/shale ratio overlay (Map 3), illustrates the variability of the sand to shale ratio and it is important to note that in Townships 15 and 16, Range 29, the sand:shale ratio increases dramatically. This overlay also indicates an increase in sand content in an up-dip (north-northwest) direction.

C. Cretaceous

Previous studies have shown that an unconformity exists between Jurassic-Cretaceous sediments. The Swan River Formation (Cretaceous) unconformably overlies the Jurassic sediments and is not consistent in either thickness or lithology. Depending on the depositional setting the Swan River may thicken or thin, thus making the base of this formation difficult to distinguish from the underlying Jurassic sediments.

An isopach map (Map 5) of the Swan River Formation has been constructed which is thought to portray a channel system. The sand/shale map has been superimposed in Map 5. These channels are found mostly in the northern portion of the study area and appear to trend northeast-southwest. Evidence to support this channelling theory is found in two wells which have been drilled recently by Troy Oils Ltd. (A4-22-16-29W1, 1-21-16-29W1) and will be presented later in this discussion.

The top of the Second Specks Formation is the best marker throughout the entire study area and it has been used as a datum in the stratigraphic cross-sections due to its consistency. It is recognizable due to its characteristic high resistivity. A structure contour map (May 6) on the top of the Second Specks has been constructed which portrays a gradual southwestward dip of the these strata. The general trend of the Second Specks appears to mimic the overall structure of the Lodgepole as do the other maps which have been constructed.

An isopach map (Map 7) from the top of the Second Specks to the top of the Lodgepole has also been constructed. This map appears to reflect the overall structure of the Mississippian erosional surface despite the existence of an unconformity which occurred prior to Cretaceous channelling and deposition. A general thinning trend occurs to the north-northeast with several localized thins in Township 15. A major low or thickening also occurs in the eastern portion of the map area and this low is also reflected on the Mississippian erosional surface (Map 1). The lower Cretaceous consists mostly of a shaley sequence with either intermittent or interbedded sandstones. Problems in sampling and coring result due to the poorly consolidated nature of the sediments.

III. Depositional Systems

Deriving a depositional model for any geologic setting is difficult and in many cases more than one model may be postulated. In this report two depositional models will be postulated for the deposition of the Jurassic and Cretaceous sediments. The first model to be discussed will explain the depositional setting in terms of Cretaceous channelling and marine Jurassic deposition, while the second model will explain the depositional setting in terms of only marine Jurassic deposition.

The red bed and evaporite sequence of the Watrous formation are prominent in the southwestern corner of Manitoba but eventually pinch out in the southern portions of the designated study area (i.e., Township 12). Overlying the Mississippian erosional surface where the Watrous is not present is what is referred to as a silty-shaly sequence deposited as a result of transgressing Jurassic seas. Towards the end of Jurassic time the sea retreated and at the end of Jurassic time a period of erosion occurred causing a great thickness of Jurassic (Vanguard) sediments to be removed. During this period of erosion, most of the middle and upper Vanguard was eroded.

In the case of the first model, the author speculates that, Cretaceous channelling took place after much of the upper Jurassic sequence had been eroded. These channels subsequently cut down into the remaining Jurassic (Vanguard and Shaunavon) sediments. The channels were in turn filled with clean sands which were bounded by interdistributary silts and muds. In this type of a setting a clean sand may become shaly over a very short lateral interval in passing from the channel to the overbank deposits. The result of having the coarser sandy material in the channel and the finer shaly material deposited as interdistributary silts and shales is that the oil is able to migrate from the Paleozoic into the sandstone bodies where it is ultimately trapped by the finer interdistributary sediments which are non-porous and impermeable.

Evidence for the channel theory is found in two wells in the immediate area of the oil discovery at St. Lazare. In the discovery well (Troy St. Lazare 1-21-16-29W1) the oil/water contact is found at -442 m K.B. while in the well immediately adjacent to it (Troy St. Lazare Prov. A4-22-16-29W1) the oil/water contact is found at -450 m K.B. Thus, if the logs from the two wells are superimposed one sand would appear to overlie the other, with the base of the reservoir unit in 1-21-16-29W1 overlying the top of the reservoir sand in A4-22-16-29W1. It is postulated by the author that the reservoir sand in A4-22-16-29W1 represents a channel deposit which has been deposited on the Mississippian erosional surface. This would seem to indicate that the sands from 1-21 and A4-22 are totally different deposits. Therefore, it is important to try and decipher where the channel has been cut and to try and determine what type of sinuous pattern the channel follows.

In the writer's view there appears to be at least two problems with the previously proposed 'Cretaceous channelling theory', even though it is possibly the best theory in principle.

The first problem is that the oil/water contact evidence presented previously appears to be the only evidence supporting the theory. Secondly, the electrical well logs used for correlation purposes do not seem to illustrate channelling in the Shaunavon Formation. Although good correlatable markers are difficult to distinguish in the northern parts of the map area it is difficult to believe that poor correlations are the direct result of channelling deep into the Jurassic. Perhaps channels do occur further up in the section as is illustrated by the broad flat base of the Swan River, but at this point the evidence for channelling deeper in the Jurassic section is suspect.

The second possibility for a depositional model is that the reservoir sands are actually marine sand deposits. From core descriptions the sands can be described as medium to coarse grained, well sorted, relatively unconsolidated, quartzose sandstone. The shallow depth of burial would allow for the preservation of porosity and permeability. The exact aerial extent of the reservoir sand is difficult to distinguish since only sparse well control is exhibited in Township 16. However, the author believes that the reservoir sand may be limited in its extent even though a stratigraphically equivalent unit, which consists mainly of interbedded siltstones, sandstones and shales, is much more aerially extensive. It is difficult to speculate which type of marine deposit the reservoir unit represents due to the lack of lithologic evidence.

It is the writer's opinion that the reservoir in A4-22-16-29W1 represents a channel deposit of either Jurassic or Cretaceous age. Despite the fact that hydrocarbons have been observed in adjacent wells it is believed that the most prospective areas for hydrocarbon occurrence will occur where the channel has been cut to the Mississippian unconformity and subsequently filled with a clean reservoir sand which has undergone very little diagenesis. However, as previously mentioned, delineating this channel may be a difficult task.

IV. Summary of St. Lazare Discovery

The oil discovery at St. Lazare can be summarized as follows:

1) heavy gravity (18^{o}API) oil is found in highly porous and permeable Jurassic sands at shallow depth (- 430 m K.B.);
2) the sands are medium to coarse grained, subrounded and well sorted quartzose sandstones;
3) the sands directly overlie the Paleozoic erosional surface (in this case the Mississippian Lodgepole Formation) with no intervening silty-shaly sequence of Jurassic age;
4) rapid facies changes from a clean sandstone to an interbedded sandy-shale unit may act as a barrier to migration or as a trapping mechanism for the oil;
5) water saturations calculated over the producing interval may be as low as 20% Sw (Appendix B); and
6) porous zones are found in the uppermost Lodgepole Formation and oil staining may be visible in limestone immediately below the Paleozoic erosional surface.

The accumulation found in the Jurassic (Shaunavon Formation) at St. Lazare is considered to be primarily stratigraphically controlled. The Jurassic sands found in this area display tremendous porosities and permeabilities, thus forming ideal potential reservoirs. Porosity and permeability of the sands have probably been preserved as a result of the relative absence of extensive burial effects and diagenetic processes such as cementation. Difficulties in correlating the Jurassic in the area around St. Lazare pose a problem when trying to delineate areas of possible oil entrapment. A clean sand may become interbedded with shale over a very short lateral interval even though the two facies are stratigraphically equivalent.

In order for there to be an oil accumulation in the St. Lazare area the Jurassic sands must immediately overlie the Paleozoic erosional surface. This may be the single most significant factor in the whole play concept since the oil trapped in the reservoir is believed to be migrated Paleozoic oil. If the sandstones are separated from the Mississippian by the silty-shaly transgressive sequence retardation of oil migration into the overlying sandstones will occur. In some cases it is difficult to determine from the logs whether or not this facies exists at all, and where the unit is less than 3 m thick correlations are uncertain.

Log interpretations from the study area illustrate the fact that the section is progressively lost from the base by overlap. First the Watrous is lost or pinches out around Township 12, secondly the silty-shaly sequence pinches out around Township 15 or 16 and finally the sandstone sequence, although not necessarily the reservoir unit, is deposited directly onto the Paleozoic erosional surface. It is in this sandstone sequence that minor hydrocarbon accumulations occur but it is believed that the major hydrocarbon accumulation is restricted to the channel or sequence of channels that have cut down to the Mississippian unconformity and have been subsequently infilled with clean quartzose sandstone.

V. Conclusions and Recommendations

1. Differentiation of the Jurassic and Cretaceous sediments is difficult.

2. Regional correlations can be made south to north but only a few markers can be carried to the most northern portions of the study area.

3. Cretaceous channelling may have occurred after pre-Cretaceous erosion of the Jurassic but the sandstones

deposited on the Paleozoic erosional surface do not appear to represent channel deposits.

4. Heavy oil found in the Jurassic sediments is thought to be oil which has migrated from the Paleozoic.

5. A basal Mesozoic silty-shaly sequence south of Township 15 may prevent the migration of Paleozoic oil, therefore oil is found only where sandstone immediately overlies the Paleozoic erosional surface.

6. Potential for Jurassic and Cretaceous hydrocarbon accumulations definitely occur in southwestern Manitoba.

7. Aerial extent of the reservoir sands has not been determined due to a lack of subsurface information such as drill stem testing, sampling and coring.

8. No estimates for recoverable reserves have been made but, with current heavy oil technology, recovery should not be a problem.

9. As more information becomes available detailed correlations of the Jurassic and Cretaceous sediments will be required (i.e. information from two previously licensed locations).

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APPENDIX A: DESCRIPTION OF CORE AND SAMPLES

Samples:

1)	Basco Kanage	13-21-12-28 W1
2)	CDCOG et al Kirkella	9-28-12-28 W1
3)	Rideau E. Kirkella	14-1-12-29 W1
4)	ASM-BTO et al Kirkella Prov.	16-29-12-29 W1
5)	Royalite Triad Two Creeks #1	2-3-23-27 W1
6)	KR Braborne Niss Creek Prov.	1-12-13-29 W1
7)	Narayan et al Manson	7-5-14-29 W1
8)	COCOG et al Willen	3-13-14-29 W1
9)	COCOG et al Manson	9-19-14-29 W1
10)	Monterey et al Birdtail	4-19-15-28 W1
11)	J.P. Owen Ross V.L.A. McCauley	3-33-15-29 W1
12)	IMC McCauley Prov. Pth	4-22-16-29 W1

Core:

1)	Calstan Harmesworth	6-24A-12-26 W1
2)	Lawrence et al Two Creeks Prov.	13-29-12-27 W1
3)	Calston Kirkella	5-21-12-29 W1
4)	Sapphite Hanson Town Henderson No. 1	13-28-13-29 W1
5)	Canadian Oil and Gas Reserves #1	15-10-14-27 W1

APPENDIX A

Lithologic Descriptions

A. CUTTINGS

Basco Kanage 13-21
13-21-12-28 W1

573 - 588 m (1880 - 1930 ft.)	Limestone, white-beige, oolitic, highly calcareous. Shale, medium to light grey. Siltstone, red, minor amounts.
588 - 594 m (1930 - 1950 ft.)	Siltstone, red. Shale, medium to liht grey.
594 - 600 m (1950 - 1970 ft.)	Quartz grains, fine-medium grained, white, rounded, in some cases cemented with calcite. Siltstone, red, very minor amounts.
600 - 607 m (1970 - 1990 ft.)	Dolomitic limestone, white-beige, low effervescence. Limestone, white, very finely crystalline - granular.
607 - 610 m (1990 - 2000 ft.)	Shale, black, very slightly calcareous.
610 - 625 m (2000 - 2050 ft.)	Dolomitic limestone, white-beige. Limestone, white-pink, very finely crystalline, high effervescence.

CDCOG et al Kirkella 9-28
9-28-12-28 W1

579 - 607 m (1900 - 1990 ft.)	Shale, medium-light grey, grading into a mudstone. Pyrite, bronze, fine grained. Limey mudstone, buff, more minor amounts.
607 - 613 m (1990 - 2010 ft.)	Limestone, white-pink, granular to very finely crystalline, poor porosity, tight. Dolomitic limestone, buff, more minor amounts.

Rideau E. Kirkella 14-1

14-1-12-29 W1

595 - 655 m (1951 - 2148 ft.)	Sandstone, very fine grained almost silty, white to beige, calcareous, cementing medium calcite, minor Limestone.
655 - 670 m (2148 - 2198 ft.)	Sandstone, very fine grained, white to beige. Siltstone, brick red, very minor. Limestone in minor amounts.
670 - 680 m (2198 - 2230 ft.)	Anhydrite, white, dense. Dolomite, buff, dense. Limestone, minor amounts.
680 - 695 m (2230 - 2280 ft.)	no samples
695 - 702 m (2280 - 2302 ft.)	Siltstone, brick red, abundant. Anhydrite, white, dense, minor amounts.
702 - 705 m (2302 - 2312 ft.)	Siltstone, brick red. Anhydrite, white, dense. Shale, medium to light grey.
704 - 706 m (2312 - 2316 ft.)	Limestone, white to pink, dolomitic limestone, buff, dense. Siltstone, red, minor amounts.
706 - 708 m (2316 - 2322 ft.)	Anhydrite, minor amounts. Dolomitic limestone, white to pink, dense.

ASM-BTO et al Kirkella Prov. 16-29

16-29-12-29 W1

549 - 552 m (1800 - 1810 ft.)	Shale, medium-light grey, very minor orange, slightly calcareous.
552 - 555 m (1810 - 1820 ft.)	Poor sample quality. Limestone, white, granular to very finely crystalline.
555 - 564 m (1820 - 1850 ft.)	Shale, medium-light grey. Siltstone, red, minor to moderate amounts.
564 - 570 m (1850 - 1870 ft.)	Limestone, white, fine-medium grained. Crystalline limestone. Dolomitic limestone, buff, minor amounts.

Royalite Triad Two Creeks #1
2-3-13-27W1

515 - 521 m (1690 - 1710 ft.)	Sample quality poor, shale-mudstone, medium grey-green grey.
521 - 540 m (1710 - 1770 ft.)	Shale-mudstone, medium grey to light grey. Siltstone, red. Limestone, white, minor amounts.
540 - 552 m (1770 - 1810 ft.)	Limestone, white, granular to very finely crystalline dolomitic limestone, white-beige, very finely crystalline.

KR Braborne Niss Creek Prov. 1-12
1-12-13-29 W1

564 - 576 m (1850 - 1890 ft.)	Shale-mudstone, medium grey to light grey. Limestone, white grey, granular, minor amounts. Pyrite, fine grained. Siltstone, red, minor amounts.
576 - 585 m (1890 - 1920 ft.)	Limestone, white-grey, mostly granular. Anhydrite, white, minor amounts.
585 - 588 m (1920 - 1930 ft.)	Anhydrite, white, dense.
588 - 591 m (1930 - 1940 ft.)	Shale-mudstone, medium to light grey
591 - 598 m (1940 - 1960 ft.)	Dolomitic limestone, buff, granular to very finely crystalline. Shale, medium-light grey. Siltstone, red, minor amounts.
598 - 604 m (1960 - 1980 ft.)	Siltstone, red, no porosity. Shale, medium-light grey.
604 - 607 m (1980 - 1990 ft.)	Dolomitic limestone, finely crystalline. Anhydrite white.
607 - 613 m (1990 - 2010 ft.)	Anhydrite, white, poor porosity. Dolomitic limestone - minor.
616 - 619 m (2020 - 2030 ft.)	Limestone-dolomitic limestone, pink-white. Dolomite, buff.

507 - 513 m (1663 - 1683 ft.)	Quartz grains, medium-coarse grained, subangular to subrounded, glassy lustre. Shale, grey, minor amounts.
513 - 528 m (1683 - 1732 ft.)	Shale, grey-black, gypsum frosting apparent on shale. Quartz grains, medium to coarse grained, glassy lustre.
528 - 543 m (1732 - 1781 ft.)	Shale, grey-black. Quartz grains, medium to coarse grained, rounded. Carbonaceous material, white, friable, highly effervescent.
543 - 561 m (1781 - 1894 ft.)	Sandstone, beige, fine grained, cemented with calcium carbonate, highly effervescent, appears silty to sandy in nature.
561 - 570 m (1840 - 1870 ft.)	Sandstone, white, fine grained, ranges from silt size to sand size.
570 - 579 m (1870 - 1899 ft.)	Sandstone, beige, fine to medium grained, subangular to subrounded, calcareous.
579 - 585 m (1899 - 1919 ft.)	Shale, grey-dark grey, appears limey, calcareous.
585 - 588 m (1919 - 1929 ft.)	Sandstone, white, glassy lustre, fine-medium grained. Shale, grey. Limestone, white, minor, finely crystalline.
588 - 591 m (1929 - 1938 ft.)	Shale, grey, pyrite seen within shale. Sandstone, white, glassy lustre, fine grained, subrounded, cemented with sparry calcite.
591 - 597 m (1938 - 1958 ft.)	Sandstone, white, glassy lustre, subrounded to subangular, sparry calcite cement, fair-good interparticle porosity. Shale, grey, minor amounts.
597 - 603 m (1958 - 1978 ft.)	Shale, grey. Limestone, finely crystalline, white-grey. Sandstone, a/a, minor amounts.
603 - 615 m (1978 - 2017 ft.)	Limestone, white-grey, finely crystalline, may be slightly dolomitic. Pyrite, minor.

CDCOG et al Willen
3-13-14-29 W1

500 - 512 m (1640 - 1680 ft.)	Sandstone, white-vitreous, fine grained, well sorted, good intergranular porosity, minor clay cement. Siltstone, red, porosity poor.
512 - 524 m (1680 - 1720 ft.)	Sandstone, as above. Siltstone, red, blocky siliceous. Pyrite, gold, rhombic. Mica, minor amounts. Clay minerals numerous within pore throats, mostly good intergranular porosity.
524 - 527 m (1720 - 1730 ft.)	Sandstone, as above, some with ferruginous look. Quartz grains, coarse, minor.
527 - 543 m (1730 - 1780 ft.)	Sandstone, beige, not as clear, fine-medium grained. Coal indicating a deltaic or reworked marine environment. Pyrite, minor-moderate amounts.
543 - 549 m (1780 - 1800 ft.)	Sandstone, white-beige, fine-medium grained, calcite cement, fair interparticle porosity, subangular to subrounded. Pyrite, associated with shale. Limestone, white, finely crystalline, minor.
549 - 555 m (1800 - 1820 ft.)	Limestone, white to grey, finely crystalline, porosity poor. Sandstone, as above, minor.
555 - 570 m (1820 - 1870 ft.)	Oolitic limestone, white-grey, porosity poor. Limestone, buff, porosity poor. Sandstone, cemented with calcite, minor.
570 - 576 m (1870 - 1890 ft.)	Limestone, white-grey, finely crystalline, fair porosities. Chert, white, very dense, conchoidal fracture. Dolomitic limestone, buff, dense.

CDCOG et al Manson 9-9
9-9-14-29 W1

549 - 558 m (1800 - 1830 ft.)	Shale, grey. Siltstone, red. Pyrite associated with shale.
558 - 561 m (1830 - 1840 ft.)	Sandstone, glassy appearance, fine-medium grained, subangular to subrounded, some tightly cemented with calcite.

561 - 564 m (1840 - 1850 ft.)	Limestone, white-grey, porosity poor-fair, finely crystalline, oolitic limestone, very fine.
564 - 579 m (1850 - 1900 ft.)	Sandstone, white glassy appearance, porosity poor-fair, fine grained, calcite cement. Limestone, white-grey finely crystalline. Shale, grey.
582 - 585 m (1910 - 1920 ft.)	Limestone, white-grey, finely crystalline, poor porosity, oolitic limestone - minor. Pyrite, associated with limestone.
585 - 594 m (1920 - 1950 ft.)	Limestone, white-grey, poor porosity, finely crystalline, dolomitic limestone, buff, dense, no porosity, oolitic limestone, minor. Chert, white, dense, conchoidal fracture.

Monterey et al Birdtail
4-19-15-28

402 - 408 m (1320 - 1340 ft.)	Sandstone, quartzose, medium grained, subangular to subrounded, well sorted, appears as unconsolidated grains.
408 - 433 m (1340 - 1420 ft.)	Sandstone, as above. Shaley-silty sequence, red minor amounts.
433 - 442 m (1420 - 1450 ft.)	Sandstone, white-beige, fine grained, calcite cement, poor porosity. Siltstone, red.
442 - 472 m (1450 - 1550 ft.)	Sample quality poor.
472 - 482 m (1550 - 1580 ft.)	Limestone, white-grey, finely crystalline. Chert, white, dense conchoidal fracture. Oolitic limestone, porosity poor-fair. Pyrite.

J.P. Owen Ross V.L.A. McCauley #3-33
3-33-15-29W1

427 - 454 m (1400 - 1490 ft.)	Poor quality samples.
454 - 463 m (1490 - 1520 ft.)	Oolitic limestone, white-grey, poor porosity. Limestone, white, finely crystalline.

463 - 482 m (1520 - 1580 ft.)	Poor sample quality.
482 - 494 m (1580 - 1620 ft.)	Limestone, white-pink, crystalline, poor porosity, appears to be oxidized in some instances.

IMC McCauley Prov. PTH 4-22
4-22-16-29W1

310 - 340 m (1017 - 1115 ft.)	Poor sample quality.
340 - 430 m (1115 - 1410 ft.)	Poor sample quality. Silty-shaley material, red to orange.
430 - 460 m (1410 - 1509 ft.)	Sandstone, fine grained, subangular to subrounded, oil stained, fluorescence, poorly cemented. Oil makes interpretation difficult.
460 - 478 m (1509 - 1568 ft.)	Sandstone, minor, as above. Limestone, white-grey, oil stained but in more minor amounts, slight cut.
478 - 486 m (1568 - 1594 ft.)	Sandstone, white-beige, oil stained, milk white fluorescence, chunks of bitumen present.
486 - T.D. (1594 - T.D.)	Poor sample quality.

B. CORE SAMPLES

Calston Harmsworth 6-24A
6-24-12-26W1

529 - 532 m (1736 - 1746 ft.)	Shaley-siltstone, grey, poor porosity. Anhydrite, interbedded with shales.
532 - 538 m (1746 - 1766 ft.)	Shaley-siltstone, grey, interbedded with anhydrite, very tight, no porosity. Anhydrite percentage is variable. May be almost completely shaley-siltstone with only minor anhydrite infilling small fractures. Becoming more anhydritized towards end of interval. 1.0 - 2.0' of shale may occur throughout.

538 - 542 m (1766 - 1777 ft.)	Shaley-siltstone, tightly cemented by anhydrite. Stringers of argillaceous material present throughout. Porosity poor due to cementation by anhydrite.
542 - 543 m (1777 - 1782 ft.)	Core interval missing.
543 - 544 m (1782 - 1786 ft.)	Siltstone, red, brecciated throughout, interbedded anhydrite causes poor porosity.
544 - 548 m (1786 - 1797.4 ft.)	Siltstone, red, again with interbedded anhydrite, becoming progressively more brecciated towards bottom of interval, porosity poor. Shaley siltstone, interbedded with anhydrite and red siltstone.
548 - 551 m (1797.4- 1806 ft.)	Limestone-dolomitic limestone, white to beige pin-point porosity but generally tight due to anhydrite. Interbedded anhydrite and limestone in interval. Dolomite, buff, finely crystalline, fractures filled with anhydrite.

<u>Laurence et al Two Creeks Prov.</u>
13-29-12-27W1

576 - 578 m (1888 - 1895 ft.)	Shale-mudstone, light grey to medium grey, fissile, argillaceous stringers throughout, highly calcareous.
578.7 - 578 m (1895 - 1896 ft.)	Shale, dark grey, fissility well developed, fine laminations.
578 - 578 m (1896 - 1896.5 ft.)	Limestones, fine grained, beige-greeny beige, highly calcareous, black clasts perhaps chert, glauconite, granular band of 0.5 feet of interbedded limestone and anhydrite, then back into limestone.
578 - 580 m (1898.5 - 1903.0 ft.)	Limestone, white-beige, intraformational brecia, clasts throughout (chert), pin-point to vuggy porosity, good permeability. Glauconite, green, thin bands, evidence of a marine environment.

580 m (1903 ft.)	Glauconite, green, slippery feel to rock, overall muddy, grunged up interval non-calcareous - large black clasts of chert with conchoidal fracture.

Calstan Kirkella #5-21
5-21-12-29W1

692 - 696 m (2270 - 2283 ft.)	Anhydrite, pink right. Siltstone, red-brown, scattered throughout.
696 - 698 m (2283 - 2289 ft.)	Siltstone, red brown, friable. Anhydrite, scattered - chicken wire apperance.
698 - 701 m (2289 - 2290 ft.)	Siltstone, red brown, chicken wire anhydrite again prevalent.
701 - 702 m (2290 - 2298 ft.)	Siltstone, red brown, most abundant - onlyu minor chicken wire anhydrite, 0 poor high angle fractures filled with anhydrite within siltstone.
702 - 704 m (2298 - 2301.8 ft.)	Anhydrite interbedded with dolomitic limestone, beige - greenish colour perhaps due to glauconite.
702 - 704 m (2301.8 - 2308 ft.)	Limestone, pink, tightly cemented with anhydrite. Anhydrite bands occur throughout - mottled appearance towards end of interval.
704 - 713 m (2308 - 2340 ft.)	Anhydrite bands, dolomite, mottled, buff, sharp contacts occur between dolomite and anhydrite - crinoid fossil fragments Limestone-dolomitic limestone, pink anhydritized fractures - mottled appearance may be caused by anhydrite.

Sapphire Hanson Town Henderson #1

3-28-13-29W1

610 - 611 m (2001 - 2005 ft.)	- only recovered 18' Shaley-siltstone, argillaceous stringers, yellow seen throughout interval. Shaley fissile material for approximately 3 feet grading gradually into a limey mudstone. Limey mudstone, grey-green, calcareous.
611 - 618 m (2005 - 2028 ft.)	Limey mudstone, grey-green, mottled appearance. Dolomitic limestones and green-beige siltstones interbedded with each other, calcite filled vuggy porosity in limestones, appears as solution porosity - limey mudstone, permeable and very friable.
618 - 619 m (2028 - 2032 ft.)	Dolomitic limestone, dense, limey mud material seen as interbeds within dolomitic limestone. Limestone, pin-point porosity up to vuggy porosity. Echinoderms and Brachiopods abundant in limestones, minimal anhydritic cementation.
619 - 627 m (2032 - 2056 ft.)	Limey-chalky interval occurs randomly throughout interval and in some cases ccurs interbedded with limey mudstones, limestones and dolomitic limestones. - interval consists of a 'mixed bag' of lithologies, as described above. Mostly friable and unconsolidated material which probably explains the lack of recovery. * 30' cut - only 18' recovered.

Canadian Oil & Gas Reserves UNO #1

15-10-14-27 W1

433 - 434 m (1420 - 1424 ft.)	Shale and siltstone interlaminated, grey, abundant glauconite, greenish clay, bioturbation thin sandstone beds, marine environment.
434 - 435 m (1424 - 1427 ft.)	Dolomite, fractured porosity, solution enlarged, light grey, with shale infilling, no anhydrite, abundant glauconite.

435 - 438 m (1427 - 1436 ft.)	Dolomite, graded bedding, coarsening upward cycle, light grey, abundant intraclastic bedding, 5-10% bedding planes on mudstone laminae. sequence - laminated lime mudstone grading up to intraclastic, argillaceous, spotty pin-point fracture porosity, calcareous.
438 - 441 m (1436 - 1445 ft.)	Dolomite, pinkish-grey, mudstone to skeletal wackestone, mottled pattern and no pronounced bedding, moldic porosity in skeletal grains, solution enlarged, calcareous, argillaceous. No evaporites.

APPENDIX B

Simandoux water saturation calculations have been done for three wells in the St. Lazare area. Calculations throughout the interval of interest show a range of water saturations with some as low as 20% Sw. Formulas used for the calculations are illustrated below and the actual figures are found on well logs on the pages that follow. Logs on which calculations were performed are as follows:

13-17-16-29W1, 1-21-16-29W1, A4-22-16-29W1

Formulas:

$$Sw^h = \frac{aRw}{O^m Rt} \qquad \text{where } n = 2,\ a = .62,\ m = 2.15$$

$$Vsh = \frac{Gr - Gr_{cl}}{Gr_{sh} - Gr_{cl}} \qquad \text{Clavier Curve}$$

$$Oe = OD - (V_{sh} \times OD_{sh})$$

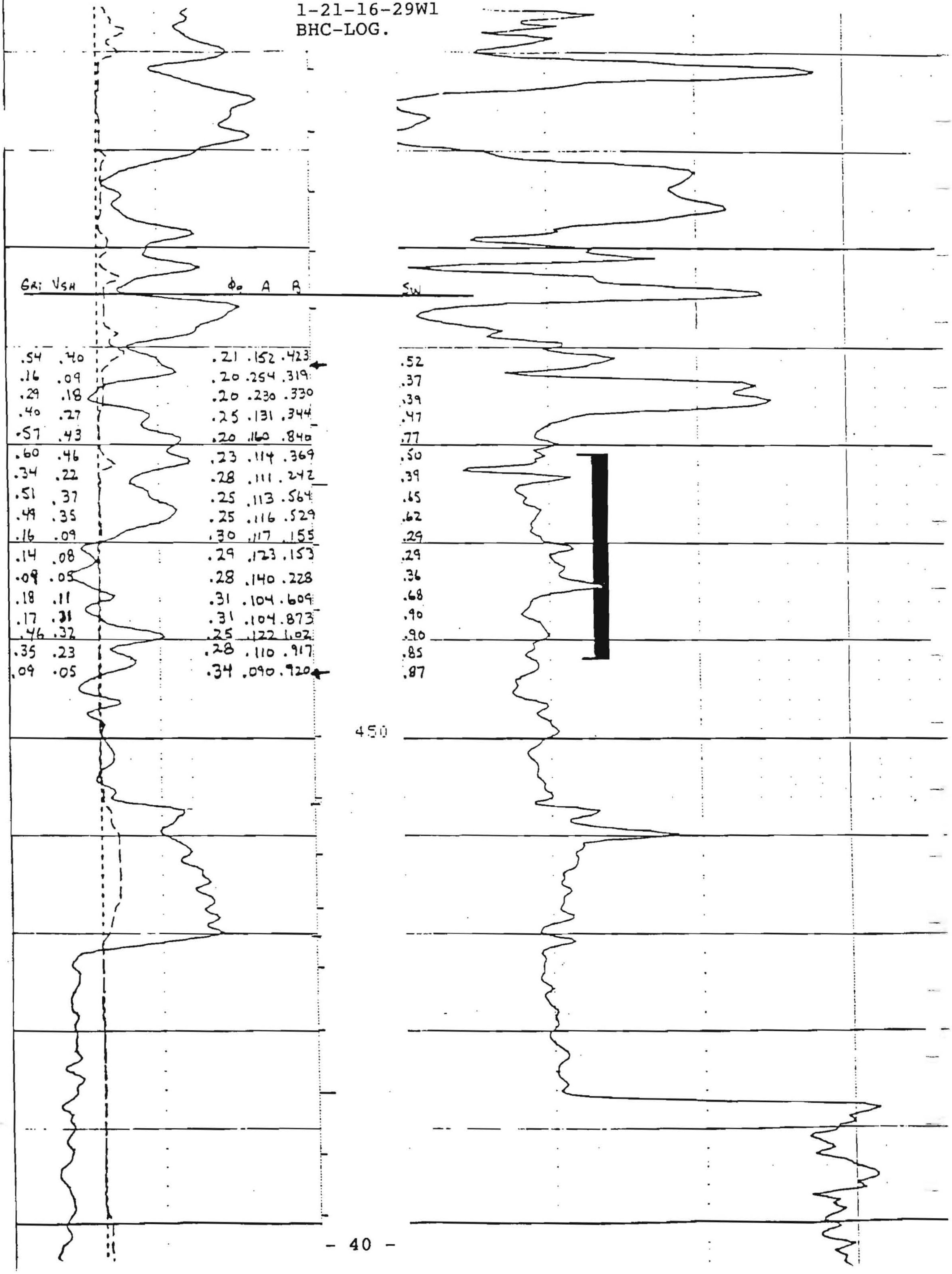
Simandoux:

$$A = \frac{.8 \times R2 \quad (1 - V_{sh})}{O_e^2} \times \frac{V_{sh}}{2R_{sh}}$$

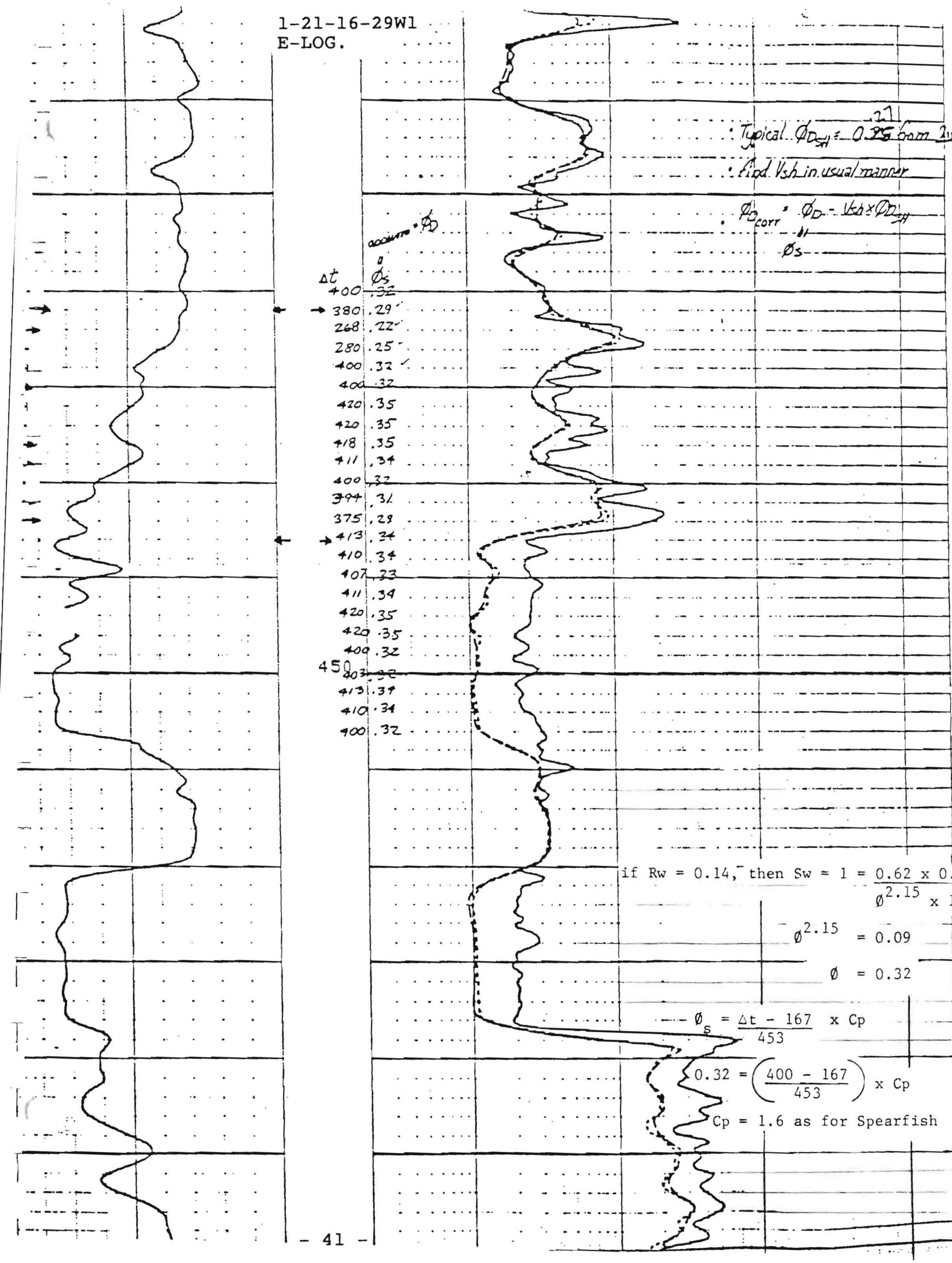
$$B = \frac{.8 \times R2 \quad (1 - V_{sh})}{O_e^2} \times \frac{1}{Rt}$$

$$SW = (A^2 + B) \quad - A$$

1-21-16-29W1
BHC-LOG.

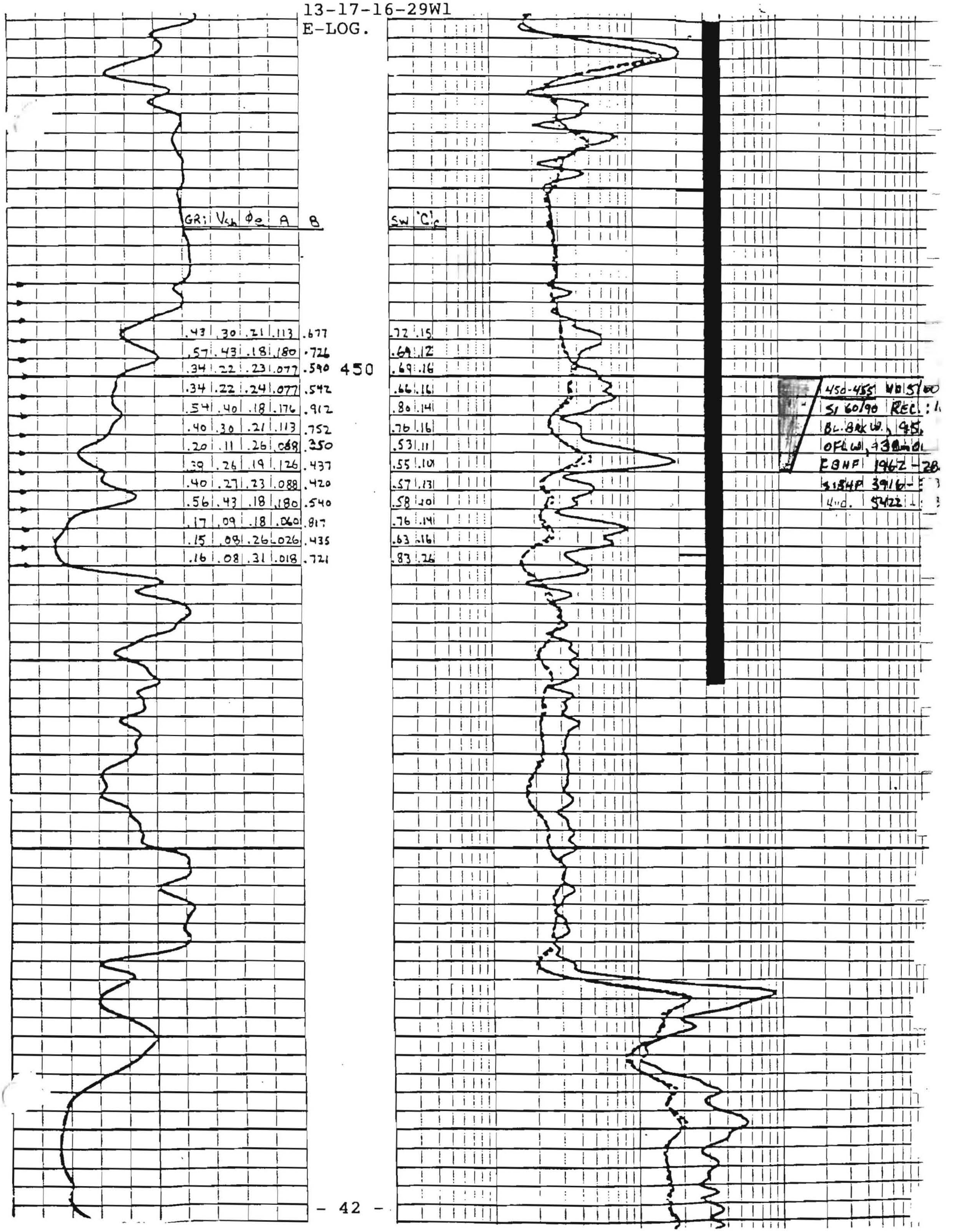


GR:	VSH	φe	A	B	SW
.54	.40	.21	.152	.423	.52
.16	.09	.20	.254	.319	.37
.29	.18	.20	.230	.330	.39
.40	.27	.25	.131	.344	.47
.57	.43	.20	.160	.840	.77
.60	.46	.23	.114	.369	.50
.34	.22	.28	.111	.242	.39
.51	.37	.25	.113	.564	.65
.49	.35	.25	.116	.529	.62
.16	.09	.30	.117	.155	.29
.14	.08	.29	.123	.153	.29
.09	.05	.28	.140	.228	.36
.18	.11	.31	.104	.609	.68
.17	.31	.31	.104	.873	.90
.46	.32	.25	.122	1.02	.90
.35	.23	.28	.110	.917	.85
.09	.05	.34	.090	.920	.87

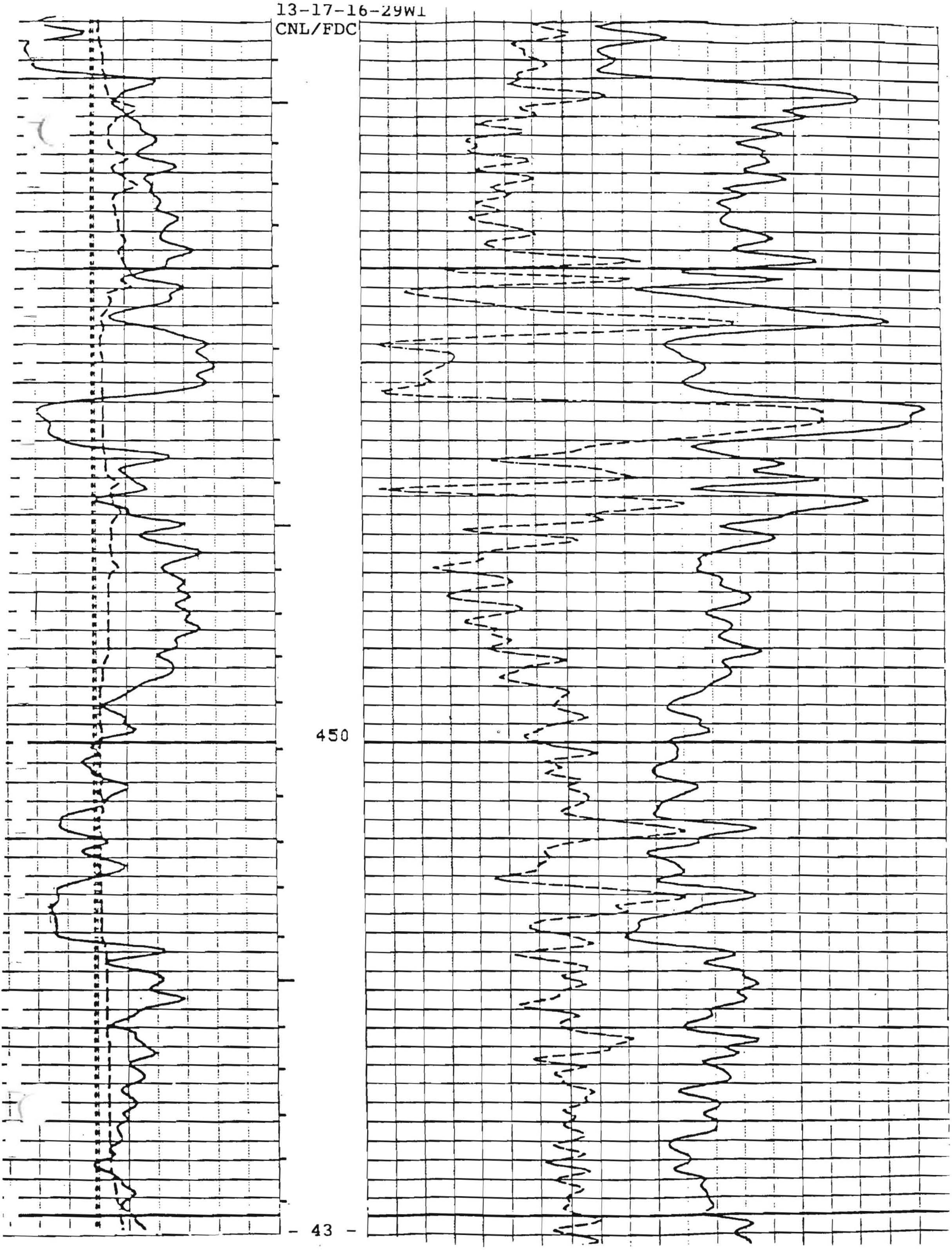


1-21-16-29W1
E-LOG.
Typical Ø_DSH = 0.~~25~~ .21 from 2 wells
Find Vsh in usual manner
Ø_Dcorr = Ø_D - Vsh × Ø_DSH
= Ø_s
accurate = Ø_D
Δt Ø_s
400 .32
380 .29
268 .22
280 .25
400 .32
400 .32
420 .35
420 .35
418 .35
411 .34
400 .32
394 .31
375 .28
413 .34
410 .34
407 .33
411 .34
420 .35
420 .35
400 .32
450
403 .32
413 .34
410 .34
400 .32
if Rw = 0.14, then Sw = 1 = 0.62 x 0.14 / Ø^2.15 x 1.0
Ø^2.15 = 0.09
Ø = 0.32
Ø_s = (Δt - 167) / 453 x Cp
0.32 = ((400 - 167) / 453) x Cp
Cp = 1.6 as for Spearfish

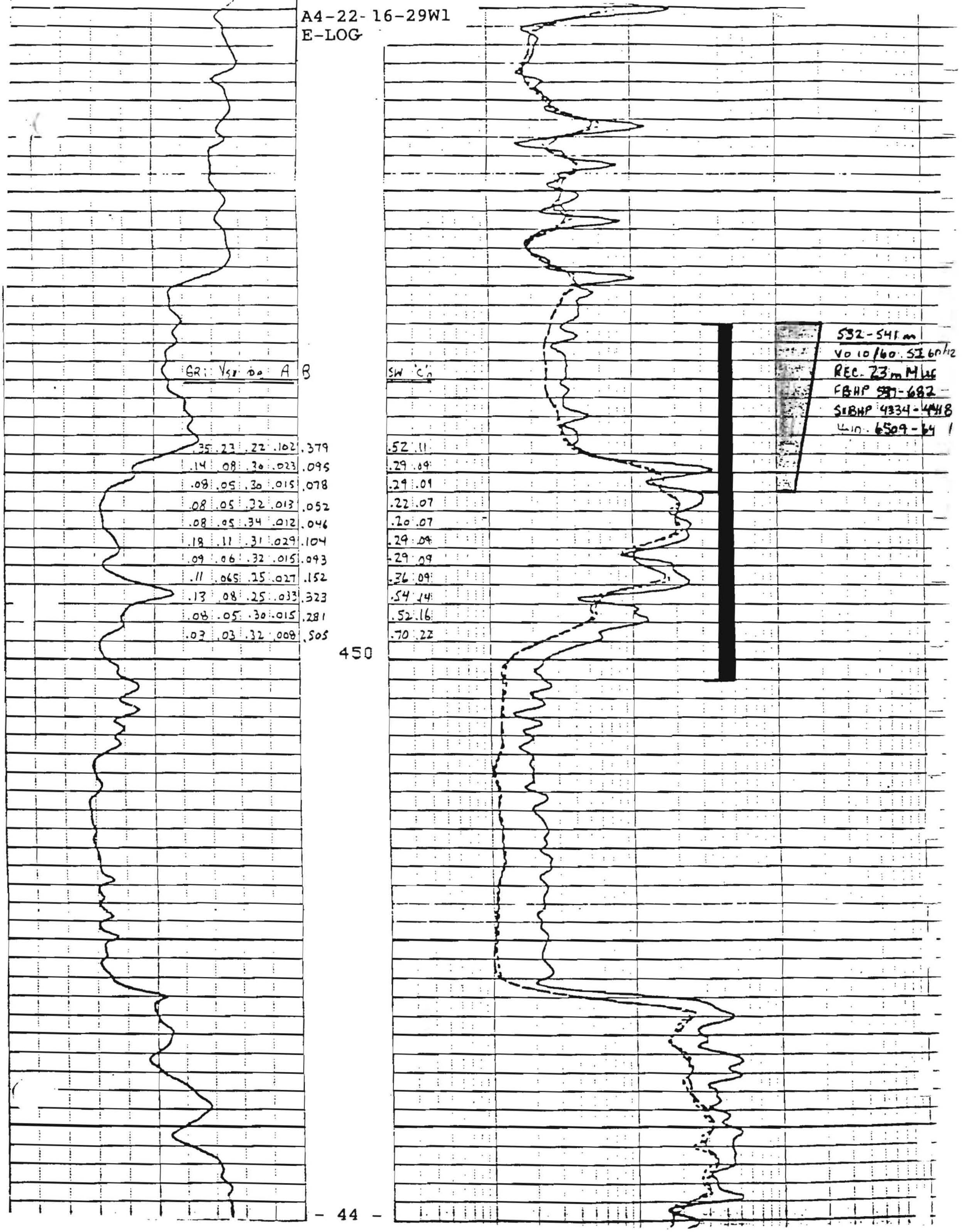
13-17-16-29W1
E-LOG.



GR:	V_{sh}	ϕ_e	A	B		Sw	C_c
.43	.30	.21	.113	.677		.72	.15
.57	.43	.18	.180	.726		.69	.12
.34	.22	.23	.077	.590	450	.69	.16
.34	.22	.24	.077	.542		.66	.16
.54	.40	.18	.176	.912		.80	.14
.40	.30	.21	.113	.752		.76	.16
.20	.11	.26	.068	.350		.53	.11
.39	.26	.19	.126	.437		.55	.10
.40	.27	.23	.088	.420		.57	.13
.56	.43	.18	.180	.540		.58	.20
.17	.09	.18	.060	.817		.76	.14
.15	.08	.26	.026	.435		.63	.16
.16	.08	.31	.018	.721		.83	.26


13-17-16-29W1
CNL/FDC
450

A4-22-16-29W1
E-LOG



GR	Vsh	Φe	A	B	SW	C'n
.35	.23	.22	.102	.379	.52	.11
.14	.08	.30	.023	.095	.29	.09
.08	.05	.30	.015	.078	.29	.09
.08	.05	.32	.013	.052	.22	.07
.08	.05	.34	.012	.046	.20	.07
.18	.11	.31	.029	.104	.29	.09
.09	.06	.32	.015	.093	.29	.09
.11	.065	.25	.027	.152	.36	.09
.13	.08	.25	.033	.323	.54	.14
.08	.05	.30	.015	.281	.52	.16
.03	.03	.32	.008	.505	.70	.22

A4-22-16-29W1
CNL-FDC
LOG.