UNIVERSITY OF MANITOBA

LYLETON AND AMARANTH RED BEDS
IN SOUTHWESTERN MANITOBA

A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

for the degree

MASTER OF SCIENCE

by

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WINNIPEG, MANITOBA

April, 1956

LYLETON AND AMARANTH RED BEDS IN SOUTHWESTERN MANITOBA

ABSTRACT

The purpose of this thesis was to determine the stratigraphic relationships between the Lyleton formation and the red beds of the Amaranth formation in southwestern Manitoba, and to determine their distinguishing lithologic characteristics.

Red beds consisting of anhydrite, dolomitic siltstone. shale, and sandstone constitute the basal unit of the Amaranth formation and are defined as the Lower Amaranth Member. This member forms a thin relatively uniform blanket of sediments overlying eroded Paleozoic strata, principally of Devonian and Mississippian age. The thickness of the unit is determined by the topography of the erosion surface, which is controlled in turn primarily by structures in the underlying Mississippian strata. The Lower Amaranth is believed to be Jurassic in age.

The Lyleton formation consists of red and green shales, with some dolomite. It contains very little coarse clastic material such as is found in the Lower Amaranth, and because of this the Lyleton can usually be distinguished from the Lower Amaranth lithologically. The Lyleton occurs only between strata of known Mississippian and known Devonian age, and is itself believed to be of Devonian age. It shows a uniform thinning towards the east until it is truncated by the pre-Amaranth erosion surface.

Detailed lithologic characteristics, environments of deposition, correlation problems, structural control of thickness in relation to oil production, and economic importance of the units are also discussed.

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LYLETON AND AMARANTH RED BEDS IN SOUTHWESTERN MANITOBA

CHAPTER I

INTRODUCTION

Southwestern Manitoba is underlain by a thick wedge of sedimentary strata that constitutes the extreme northeastern edge of the Williston Basin. This sedimentary wedge thins rapidly to the northeast where it eventually pinches out against the Precambrian basement complex.

The sediments consist of two principal units, an underlying Paleozoic sequence dipping to the west at about twelve to sixteen feet per mile, and an overlying Mesozoic and Cenozoic sequence lying unconformably on the Paleozoics and dipping more gently to the west at five to six feet per mile (Fig. 1). The whole sedimentary sequence has subsequently been partially bevelled off by Pleistocene glaciation and Cenozoic erosion and buried under a variable depth of glacial till and lake beds. Mesozoic

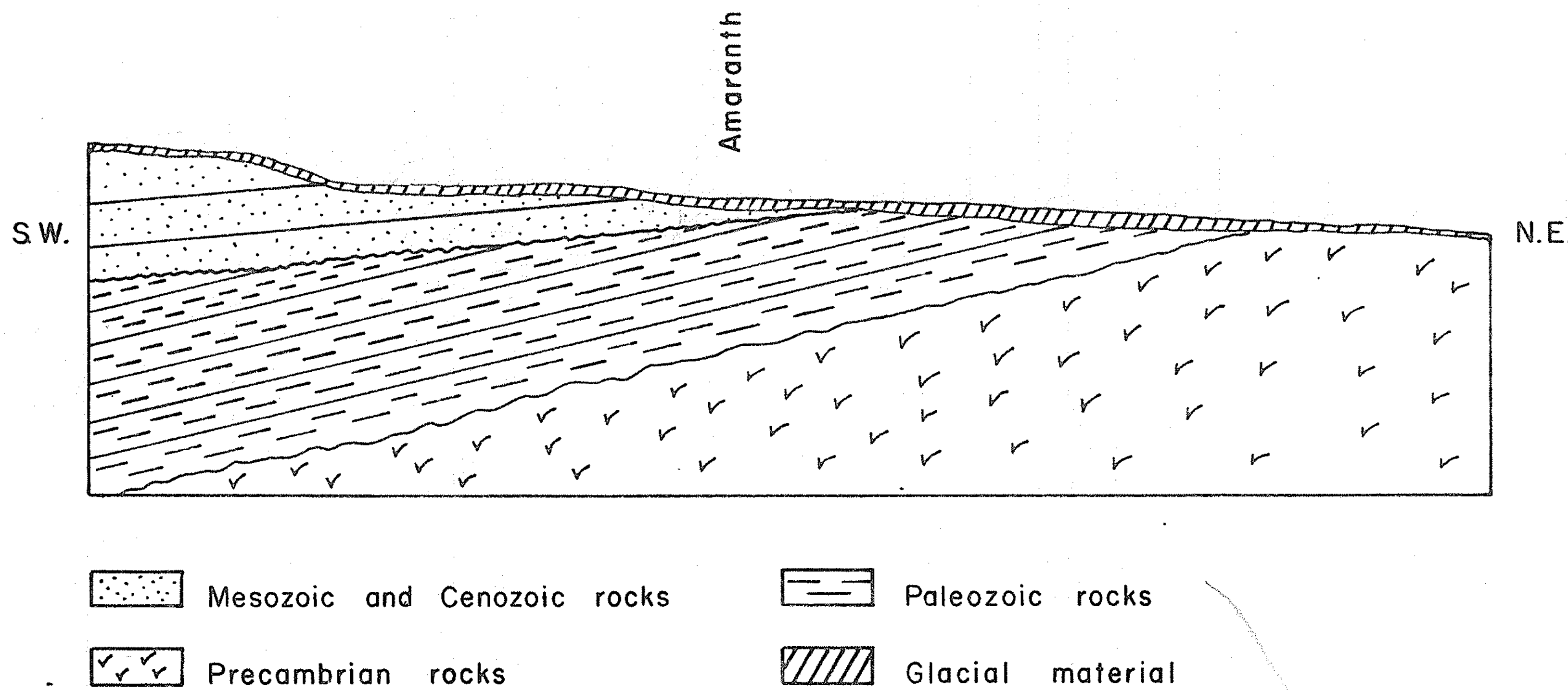


Figure. I. Diagramatic cross section showing the relationship between Mesozoic and Paleozoic rocks. Vertical scale greatly exaggerated.

and Cenozoic strata form long linear belts of outcrop trending north-north-west but largely buried under glacial material. Farther to the east Devonian, Silurian, and Ordovician strata form broad outcrop bands also trending north-north-west (Plate I).

In the area around Amaranth and Neepawa, where the overlying rocks rest unconformably on eroded Devonian, the basal member of the upper sequence is composed of a series of red silty shales, evaporites, and carbonates. These beds directly underlie known Jurassic strata and have been named the Amaranth by Wickenden (1945).

Farther to the southwest, where Mississippian strata wedge in, there are two principal red bed sequences, one overlying the eroded Mississippian surface and the other occurring between Mississippian and known Devonian strata. The latter has been named the Lyleton by Allan and Kerr (1950).

Some controversy has arisen over the relationship between these two red bed sequences. Allan and Kerr believe that the Lyleton is a separate formation, probably Upper Devonian in age, and that red beds overlying the Mississippian are correlative with the Amaranth of Wickenden. Wickenden, however, suggests that the Amaranth and Lyleton are the same unit, or, possibly, that the Lyleton and Amaranth are separate units,

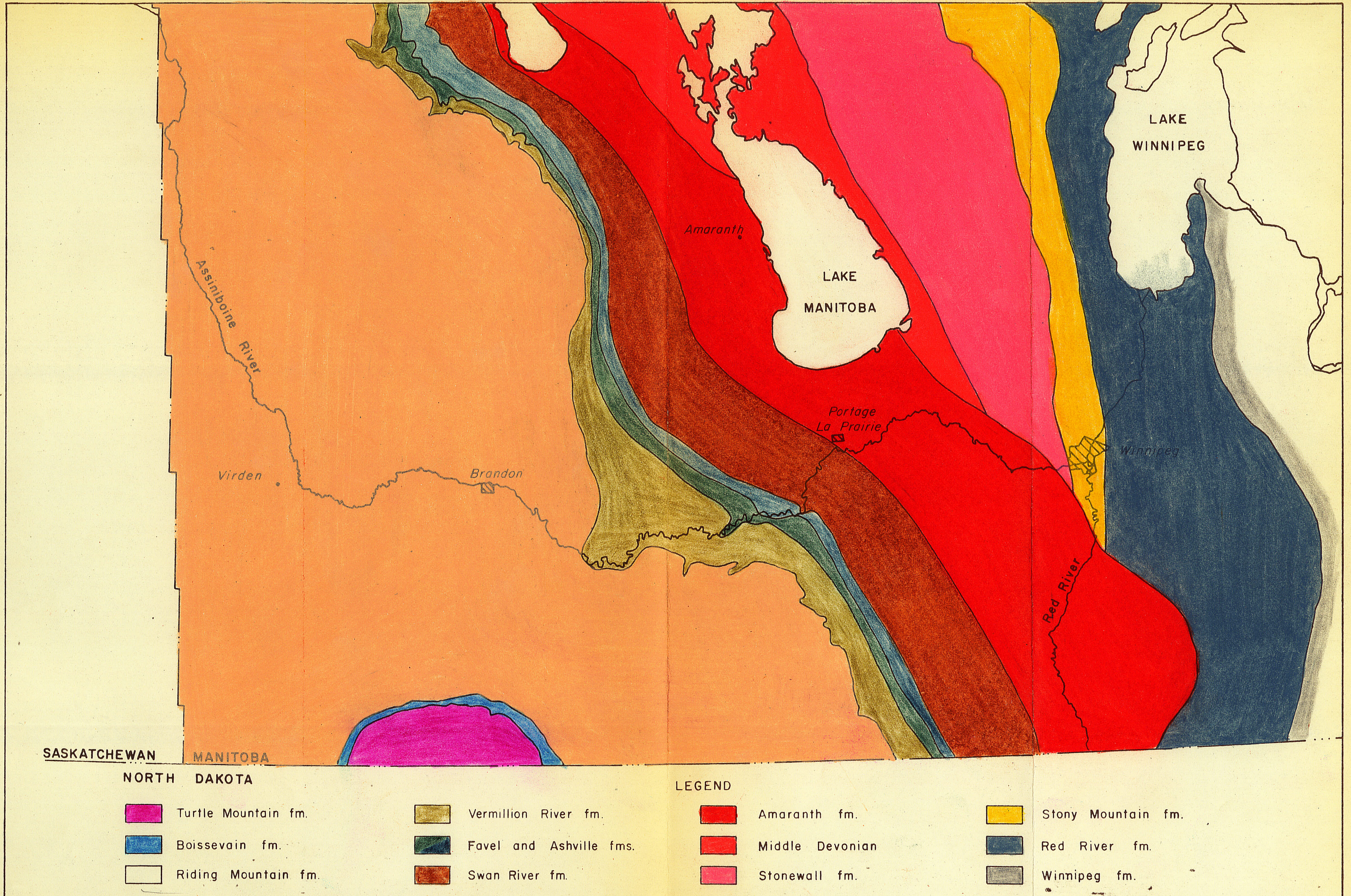


Plate 1. GEOLOGICAL MAP OF SOUTHWESTERN MANITOBA from Geological Survey of Canada Map. 850A, 1946.

and the Amaranth is restricted to the area where the Mesozoic sequence is underlain by Devonian rocks and is itself of Mesozoic age.

Purpose and Scope of the Study

The purpose of this study is to clarify the relationship between the Amaranth and Lyleton formations, and to determine their distinguishing characteristics, environments of deposition, and their general stratigraphic relations.

The area studied includes the southwestern corner of Manitoba and adjacent areas in Saskatchewan and North Dakota. It comprises approximately 30,000 square miles, as shown in Fig. 2. Detailed stratigraphic examination was confined to Manitoba, but an attempt was made to extend the correlation into adjacent areas of Saskatchewan and North Dakota using published stratigraphic information. Most of the research was carried out during the winter of 1952-1953, but some additional information is included from subsurface records up to 1955.

Acknowledgements

The work on this report was carried out under a bursary from the National Research Council of Canada, and a Scholar-

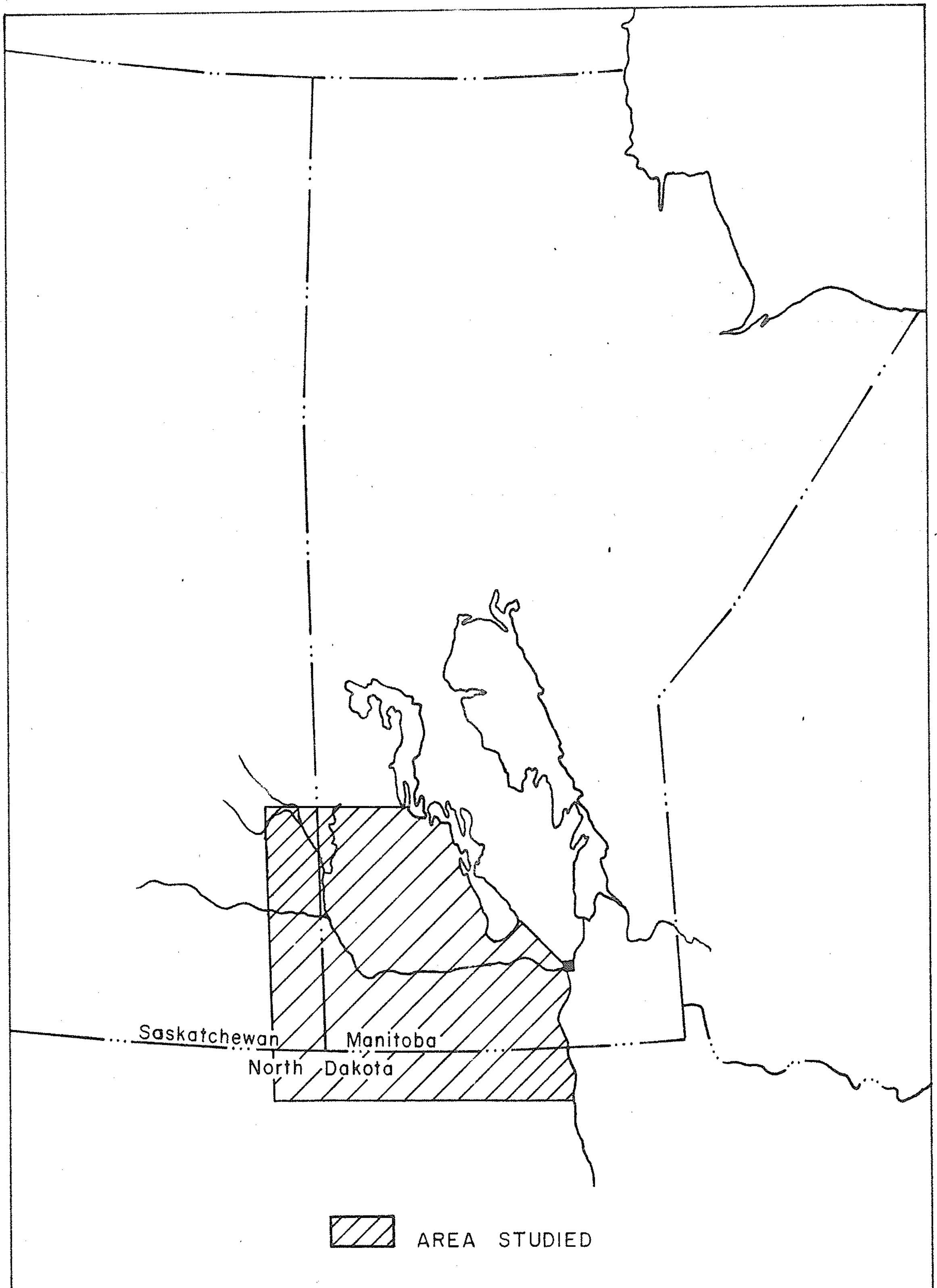


Fig. 2. INDEX MAP SHOWING AREA OF STUDY

ship from the California Standard Company, whose financial assistance are deeply appreciated.

This report was prepared under the supervision of Professor E. I. Leith of The University of Manitoba. His guidance, advice, and constructive criticism are gratefully acknowledged and many thanks are also offered to the other Professors of the Geology Department for their help.

The writer is indebted to Dr. A. D. Baillie who first proposed this problem, and contributed many helpful suggestions; and to Mr. D. R. Francis of the Saskatchewan Department of Mineral Resources who supplied much of the subsurface information for Saskatchewan.

The cooperation, assistance, and stimulating discussion with members of the Manitoba Mines Branch has been invaluable. Particular thanks are due Dr. G. H. Charlewood who permitted the writer to use the available subsurface records and laboratory facilities of the Mines Branch.

Previous Work

The Amaranth Formation -- The term Amaranth was originally proposed by Kirk (unpublished manuscript) for the Gypsum-bearing beds occurring in the mine at Amaranth, Manitoba.

Wickenden (1945) defined the Amaranth as follows:

> Devonian beds comprise the youngest Paleozoic rocks identified in the area, and Jurassic beds the oldest known Mesozoic strata. Between them lies an assemblage of red shale, gypsiferous beds, and calcareous rocks that have previously been considered Devonian, but as they are unconformable on the known Devonian beds and may or may not be conformable with the Jurassic strata, it is uncertain to what period they belong. The name Amaranth is suggested for this formation ....
> The most complete information on the sequence of these beds is obtained from well samples, and the lithological succession is contained in the logs of the Commonwealth Manitou No. 2 and Neepawa Salt Company No. 2 wells ....

In a corrigenda in the 1953 reprint of his original Memoir, Wickenden suggested the following possibilities for the correlation of the Amaranth formation:

> Studies by the author of deep wells drilled in the western part of Manitoba have revealed that no beds of red, dolomitic silt similar to the Amaranth occur above the Mississippian. The only beds at all resembling those of the Amaranth, the Lyleton, occur at the top of the Devonian and are conformable with the underlying Devonian formation. This is in direct contrast to the conditions farther east, beyond the limits of the Mississippian, where the Amaranth overlies the Devonian with marked unconformity.
> Either the Lyleton and Amaranth are the same age and the unconformity at the base of the Amaranth, in spite of its appearance, is purely local, or else, as the writer believes, the Amaranth is restricted to the area east of the limits of the Mississippian and is Mesozoic (probably Triassic) in age.

Ower (1953) divided the Jurassic into two units, A and B, with unit B corresponding to the Amaranth of Wickenden. He further subdivided unit B into subunits B-1, equivalent to the basal red, sandy, silty shale member; B-2, equivalent to the middle gypsum or anhydrite member; and B-3, equivalent to the upper carbonate member (see Table 1). The subunits are all conformable, and show gradational contacts. However, he believed that there was a minor, but definite, hiatus separating units A and B, at least in the Daly area.

Ower considered that the upper B-1 and B-2 subunits were equivalent to the Jurassic Gypsum Spring formation of Wyoming and Montana, and as these strata grade downward with no visible break into the red beds, he believed the entire Amaranth formation to be Jurassic in age.

Schmitt (1953) believed that the upper carbonate member, or B-1 could be correlated with the upper oolitic zone of the Middle Jurassic Piper Limestone of eastern Montana and North Dakota. The latter is equivalent to the Gypsum Spring formation of Wyoming and the Black Hills. He placed the base of the Jurassic section somewhere below this oolitic limestone, and included the red beds partly in the Lower Jurassic and partly in the Upper Mississippian Big Snowy group. He did not believe that Triassic

ROCK UNITS	WICKENDEN	OWER	MANITOBA SCHEDULE OF WELLS	MANITOBA (STOTT)	MONTANA	SCHMITT	SASKATCHEWAN	NORTH DAKOTA
LIMESTONE		JURASSIC B-1	JURASSIC LIME				GRAVELBOURG	
EVAPORITES (SOME SHALE)	AMARANTH	JURASSIC B-2	JURASSIC EVAPORITES	AMARANTH	GYPSUM SPRING	PIPER		PIPER
RED BEDS		JURASSIC B-3	JURASSIC RED BEDS		SPEARFISH	BIG SNOWY	WATROUS	
	DEVONIAN							SPEARFISH

Table. I. Various Systems of Nomenclature Proposed for the Amaranth Formation.

rocks were present in the map area (see Tables 1 and 2).

In recent Manitoba Government reports (Zaborniak, 1954; and Schedule of Manitoba Oil Wells) the Amaranth is divided into three units which correspond to the subunits B-1, B-2, and B-3 of Ower, and are called Jurassic Lime, Jurassic Evaporites, and Jurassic Red Beds respectively. Previous to this the terms Amaranth, Spearfish, and Gypsum Springs were used for this unit, or for various subdivisions of it, by the Manitoba Government Survey, and also by a number of oil companies.

Stott (1955) uses the term Amaranth as originally defined by Wickenden, but believes it is of Jurassic age and correlates it through the entire southwestern part of Manitoba, where it rests on Mississippian as well as Devonian rocks. He divided the Amaranth into two units, the Upper and Lower Amaranth with the upper consisting of both the evaporites and carbonate, and the Lower Amaranth consisting of the red silty shales and siltstones.

The Saskatchewan government has proposed several classifications for Jurassic strata. The "J" classification was proposed in 1952. . In this classification the Jurassic Lime, or B-1, was called the J-4-A, and the Red Beds and Evaporites the J-4-B. Recently Milner and Hadley (1953) revised this

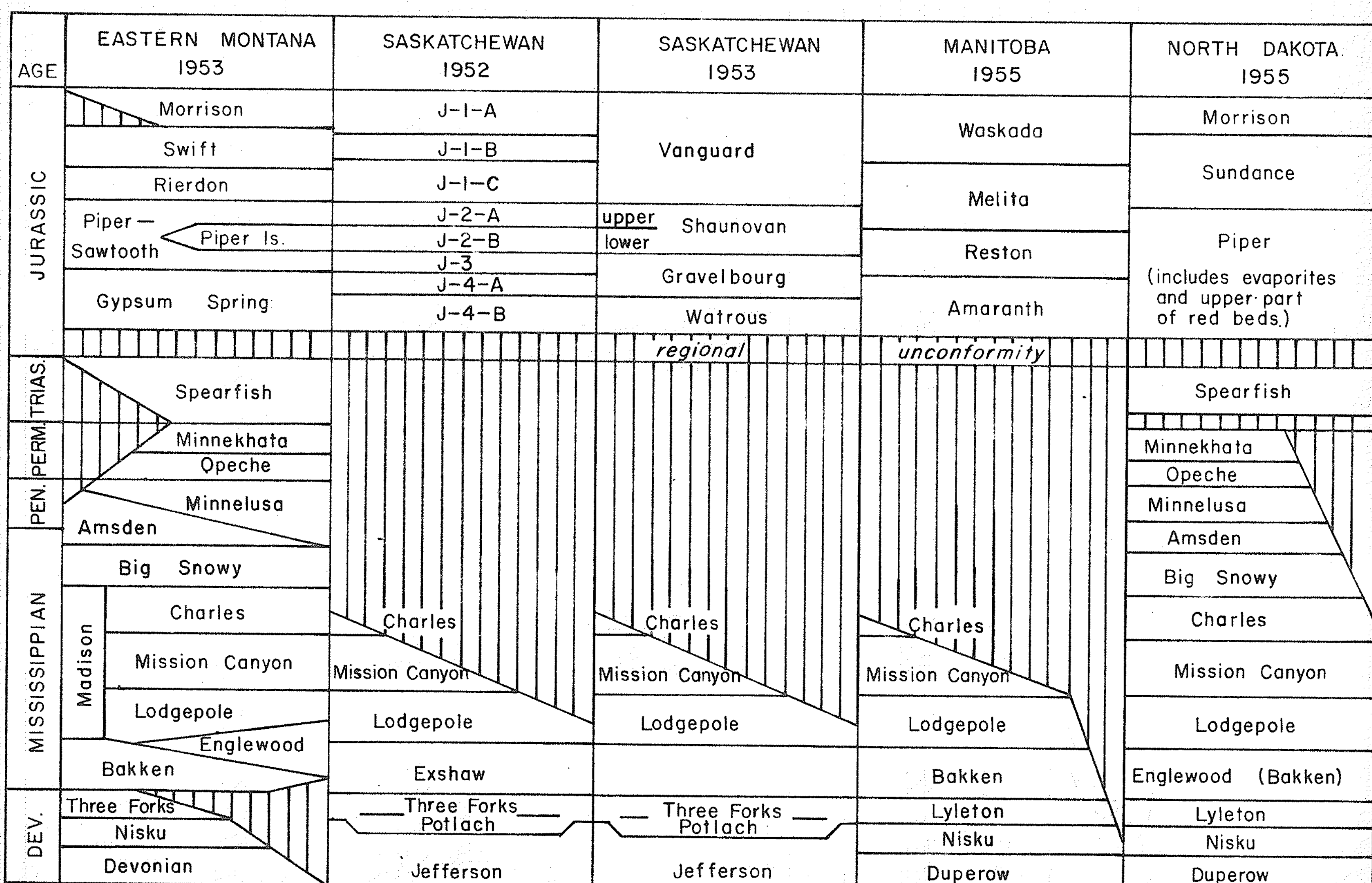


Table 2. CORRELATION CHART.

classification. They included the Jurassic Limestone equivalent in the lower part of the Gravelbourg formation, and the Evaporites and Red Beds in the Davidson (now called Watrous) formation.

The North Dakota Geological Survey, previous to 1954, called the entire red bed and evaporite sequence between known Jurassic and Paleozoic strata the Triassic Spearfish formation, but Towse (1954) in a recent change in correlation included the Evaporites and part of the Red Beds in the Piper formation of Middle Jurassic age, as defined by Imlay, 1946. He correlated only the lower part of the red bed sequence with the Spearfish formation. The Spearfish, however, apparently does not extend into the map area, and is confined to the more central parts of the Williston Basin.

The foregoing section on the various systems of nomenclature that have been applied to the Amaranth, as originally defined by Wickenden, is summarized in Tables 1 and 2. As the term Amaranth has definite precedence in the literature; as it is quite accurately defined by Wickenden; and because no direct correlations have yet been worked out for this unit, the writer will use the term Amaranth throughout this thesis.

Definition of the Amaranth Formation as Used in this Report. -- The writer agrees with Wickenden's definition of the Amaranth in the type area, but does not agree with his later statement (corrigenda; 1953) that "no beds of red dolomitic silt similar to the Amaranth occur above the Mississippian." The red shales, gypsiferous beds, and calcareous rocks comprising the Amaranth formation constitute a nearly continuous sequence of strata overlying eroded Devonian and Mississippian rocks in the map area. The writer would thus expand Wickenden's definition somewhat to include in the Amaranth formation the assemblage of red shale, gypsiferous beds, and calcareous rocks underlying known Jurassic rocks, and overlying eroded Paleozoic strata in southwestern Manitoba.

This definition of the Amaranth formation will be used throughout this thesis, but it should be noted that to the southwest of the map area the above definition does not apply, as earlier Mesozoic rocks of the Triassic Spearfish formation are believed to be present below the Amaranth.

The Red Bed, Evaporite, and Carbonate units will be referred to respectively as the Lower Amaranth, Middle Amaranth, and Upper Amaranth members of the Amaranth formation.

The Lyleton Formation: -- In 1949 two wells, the Gordon White No. 1, and the Robert Moore No. 1, were drilled near the town of Lyleton and encountered a previously unknown red bed section between known Devonian and known Mississippian strata. Allan and Kerr (1950) named these red beds the Lyleton formation, and proposed the occurrence at the Gordon White No. 1 well as the type section for the Lyleton.

The Lyleton is composed predominently of red shale with minor amounts of reddish-brown or pale green dolomite. It is not fossiliferous, and its exact age cannot be determined. However, according to Allan and Kerr, its stratigraphic position is similar to that of the Upper Devonian Three Forks formation of Montana and North Dakota. They tentatively classified the Lyleton as Upper Devonian because no basal Mississippian beds are known that are lithologically similar to it.

At that time little was known about the distribution of the Lyletom. It was found in the Robert Moore No. 1 well three and one half miles north-east of the type section at Gordon White, but no similar red beds were present in the California Kamp No. 1 well in North Dakota. However, approximately sixty feet of red shale and reddish buff finely crystalline dolomite of known Upper Devonian age were found in the Carter Semling No. 1 well, also in North Dakota. Ehlers (1943) suggested that the latter red beds were equivalent to the Amaranth of Manitoba, but Allan and Kerr believed that they correlate with the Lyleton of Manitoba.

Baillie (1949) did not recognize the Lyleton exposed anywhere in surface outcrop in Manitoba. In 1953 he included the Lyleton in the Qu'Appelle Group of Upper Devonian age, and stated that it was apparently conformable with the underlying Devonian Nisku formation, and also with the overlying Mississippian strata. He believed that the Lyleton does not occur beyond the limit of the Mississippian cover, with the possible exception of a thin peripheral band,* and that it shows quite complex lateral or facies changes. To the west it becomes unrecognizable as a mappable unit in the silty, argillaceous, and anhydritic strata of the Qu'Appelle Group. Baillie indicated that in southern North Dakota, the Lyleton thickens and changes to a limestone and argillaceous limestone unit which may or may not contain red beds.

Ower (1953) correlated the Lyleton with the M-1, and M-2 members of the Moosejaw formation of Saskatchewan; the Wabamun, Graminia, and Calmar of Alberta; and the Three Forks and Potlach of Montana.

* Paleogeologic Map, Plate 4.

Sources of Data and Methods of Study

The study consisted primarily of a laboratory examination of core and well cuttings from the Amaranth and Lyleton formations. The methods of examination included: petrographic examination of thin sections, insoluble residue analysis, X-ray analysis of the fine fraction of the insoluble residues, and binocular examination. These studies were made in order to find, if possible, a method for distinguishing between the Amaranth and Lyleton formations, and to determine their environments of deposition. The accumulated data were then applied to a regional stratigraphic analysis of these formations.

When this study was initiated, only a few wells had been drilled in Manitoba, and the majority of these were drilled only as far as the upper part of the Mississippian section. Few wells were drilled deep enough to encounter the Lyleton formation. There was consequently a very marked lack of subsurface data, especially for the Lyleton; however, during the study there was a continual and rapid accumulation of new information from recently completed wells, but the core from many of these wells was not available for study at that time.

Another reason for the lack of subsurface information on the Amaranth and Lyleton is that in most oil wells these units are not cored as they have not proved to be of commercial value as potential producing horizons.

The lithologic nature of the units also contributes to the lack of information. The Amaranth, especially, consists largely of a very friable, shaly, dolomitic siltstone to sandstone which shows very poor recovery in the well cuttings. By far the greatest part of the samples are lost in the drilling and washing of the samples. Prior to washing, the samples are frequently bright red due to a fine silty coating on the cuttings, but on washing the red material is almost always lost, leaving only shale cavings from the overlying formations. The Lyleton is generally a more dolomitic, better consolidated unit, and the well cuttings are better than those from the Amaranth.

Sampling Methods -- The procedure followed in sampling the well cores was to take hand specimens every two feet, or every change in lithology. Also, chip samples were taken over every two foot interval, or every lithologic unit. Insoluble residue analyses were made of all chip samples, and thin sections and polished sections were examined for selected hand specimens.

Preparation of Material -- In the laboratory examination, a number of techniques were employed to which the writer had not seen previous reference. These techniques formed an important part of the study and will be described in some detail in the following sections.

Considerable difficulty was encountered in preparing thin sections from many of the specimens. Many of the thin sections could not be ground down to the required thickness, using standard techniques, due to the fine porosity and poor cementation of the siltstones, and their resulting friability. Also, many of the shales showed a marked tendency to disintegrate on wetting, and it was found to be impossible to make thin sections of these specimens by any means.

The specimens were impregnated with a solution of Bakelite plastic by soaking the rock sections in the plastic and then heat treating the impregnated sections in an electric furnace at about 105^{o} centigrade for six hours. This, however, proved to be of little value for most specimens as the pore spaces were too fine to permit penetration by the relatively viscous plastic.

The fluidity of the impregnating solution was increased by diluting it with ethyl alcohol and it was then forced into the specimen under pressure. The specimens to be impregnated were placed in the dilute impregnating solution in a heavy, air tight, glass jar, which was then connected to a high vacuum pump and evacuated. Most specimens showed strong effervescence as the air was drawn out of the pore spaces. The pump was then switched over to pressure to force the plastic into the evacuated pores. The vacuum-pressure impregnated specimens were then heat treated as before and the thin sections prepared by the standard methods.

Much better results were obtained using this technique, though it was still impossible to prepare thin sections of some of the more friable specimens. Slightly better results were obtained if the specimens were evacuated before the addition of the plastic.

In the usual procedure for thin sectioning rock fragments, or sand grains, the fragments are cemented on a glass slide with plastic or balsam, and the grains are then ground down to the desired thickness. This method was not satisfactory, however, because the lower surfaces of the fragments were not a plane surface but merely the original rough surface of the fragment. This made a petrographic examination difficult and inaccurate, especially when the surface of the fragment is is stained, frosted, and pitted, as are the sand grains from the Amaranth.

To overcome this difficulty, the fragments or sand grains were placed in a suitable glass or cardboard container, covered with Bakelite plastic, and then heat treated at about 100° centigrade for twelve hours to produce an artificially cemented sandstone or breccia which was then thin sectioned in the standard manner. The plastic tended to warp considerably during the grinding and mounting, but generally satisfactory results were obtained. For finely porous and friable specimens, the method was modified to include the pressure impregnation technique described previously.

Insoluble Residue Analysis -- Insoluble residue analyses were made on most of the chip samples using standard procedure (Twenhofel and Tyler, 1941) but several problems were encountered that affected the interpretation of the results.

The purpose of the analyses was to ascertain if the Amaranth or Lyleton formation showed any residue characteristics that might serve to distinguish between the two formations.

The chip samples were reduced to -4 mesh by crushing in a large steel mortar and pestle. A sample of approximately 30 grams was weighed out, placed in a 150 millilitre beaker, and treated with hot, 20 per cent commercial muriatic acid several times until all reaction had ceased. The residue was then washed thoroughly, dried, weighed, and stored for further qualitative examination.

Ordinarily, the loss in weight of the specimen represents the amount of carbonate in it. Many of the Amaranth specimens, however, contained much anhydrite, which is slightly soluble in water, and "soluble in acid" (Handbook of Chemistry and Physics, 1953). At first it was thought that the anhydrite would be dissolved by the acid treatment, but it was found that, in samples where anhydrite was an abundant constituent of the rock, the anhydrite was retained in very considerable amounts in the residue.

The loss in weight of the sample was thus due to two factors:

(1) solution of the carbonate.

(2) total or partial solution of the anhydrite, depending on the amount present in the sample, and the grain size of the fragments.

The second factor renders the results somewhat unsatisfactory as a means of determining the percentage of carbonate, or the rock type, from the percentage of soluble material. Consequently, the application of the quantitative results of the insoluble residue analyses for correlation purposes are somewhat restricted.

The insoluble residue was divided into fine, medium, and coarse fractions by settling and decantation. The fine fraction, consisting of clay to fine silt was examined by X-ray techniques. The medium size fraction, composed of clay aggregates and fine silt size particles, was not examined as it was too fine to be studied by petrographic methods. The coarse size fraction composed of coarse silt, sand, and any other coarse insoluble material was studied by several different methods. The size, shape, roundness, sphericity, and surface textures of the grains were observed under the binocular microscope, and, for a more detailed study, the grains were mounted in balsam and studied under the petrographic microscope, or were thin-sectioned using the plastic mounting technique described previously.

The writer did not attempt grain size analyses of the residues because no satisfactory method for disaggregating the clay fraction could be devised. However, grain size estimates were made from the thin sections using the petrographic microscope with a micrometer eyepiece.

Heavy Mineral Analysis -- Heavy mineral separations were also made on a few of the samples showing the highest percentage of coarse insoluble residue, and the heavy mineral fraction was examined under the petrographic microscope. Bromoform, density 2.9, was used in the separation following the method outlined by Twenhofel and Tyler (1941). Unfortunately, when bromoform was used, anhydrite (density 2.96) was retained in the heavy mineral fraction. It was generally very much more abundant than any of the other heavy minerals, and, as only those heavy minerals other than anhydrite were of interest, the separation was rather unsatisfactory. Consequently, only a few samples were examined in this way.

X-Ray Analysis -- The fine fractions from the insoluble residue analyses were mounted on a fine glass rod, and standard X-ray powder diffraction photographs were taken. Cameras of 2.765 centimeter radius were used, with Copper K-θX radiation and and a nickel filter. This method, however, was not too satisfactory, as it was difficult to determine some of the larger lattice spacings of the clay minerals. The 18 Angstrom line for montmorillonite could not be read at all, as it was cut out by the direct-beam trap. Much better results would have been obtained using a larger camera. Nevertheless, the results were satisfactory, even though the pronounced darkening in the low θ region made identification of the lines in this area quite difficult.

CHAPTER II

DESCRIPTIVE STRATIGRAPHY OF THE LYLETON FORMATION

Definition -- The Lyleton formation, as defined for the map area, is the assemblage of red to green dolomitic shales occurring between the Mississippian Bakken formation, and the Devonian Nisku formation. To the south of the map area the Bakken pinches out and the Lyleton is directly overlain by the Mississippian Englewood or Lodgepole formation.

Electric and Radioactivity Log Characteristics -- The Lyleton is characterized by uniformly low values of resistivity and Spontaneous Potential (S.P.), with only a few minor peaks on both curves. The radioactivity log shows generally high readings, but is extremely variable (Fig. 3 and 4).

The base of the Lyleton is easily picked on electric and radioactivity logs due to the marked contrast with the underlying Nisku formation, which shows high S. P. and resistivity, and low radioactivity values. The upper contact of the Lyleton is usually very difficult to pick on the mechanical logs due to the similarity of the characteristics of the Bakken formation.

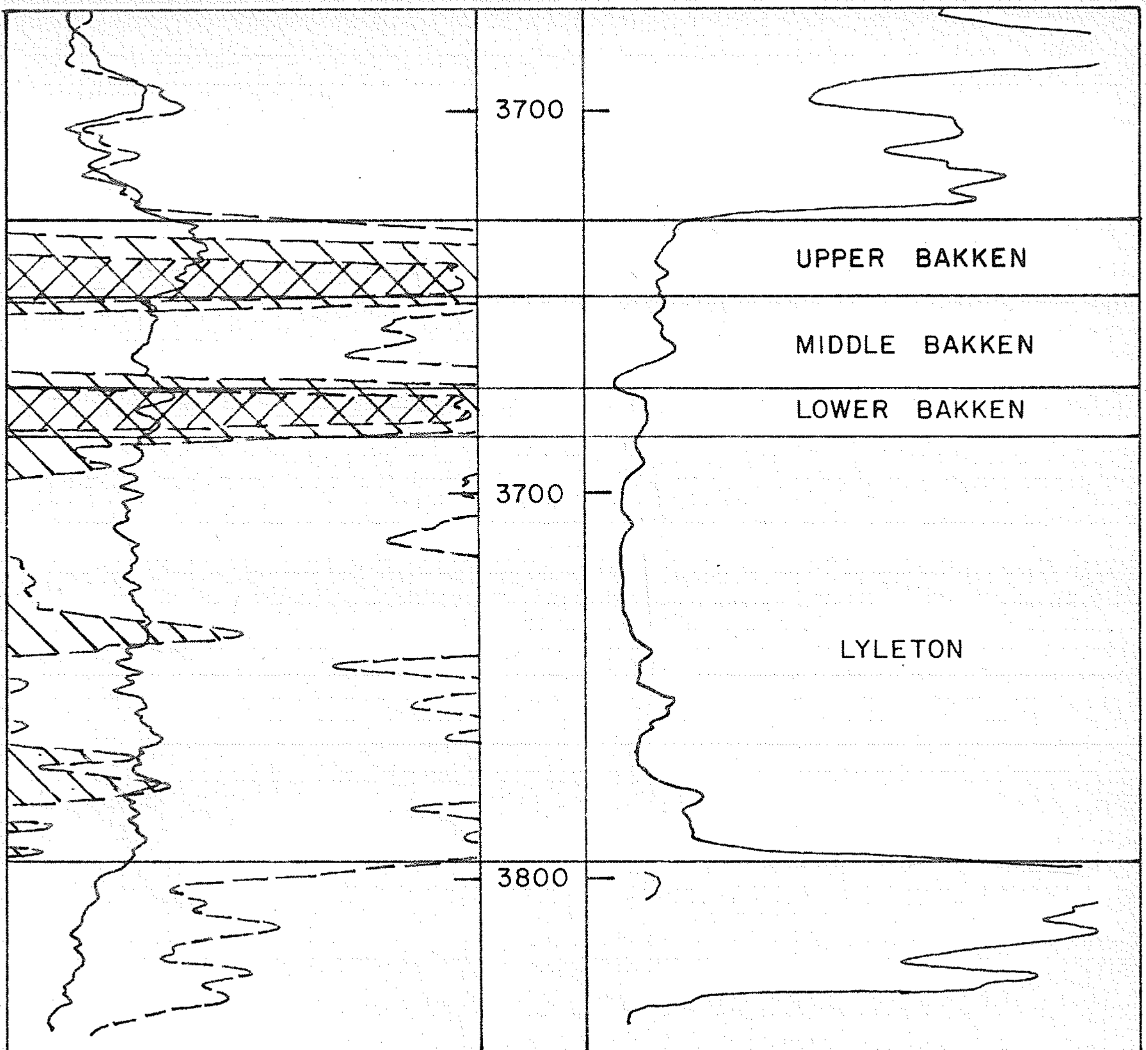


Fig. 3. CALIFORNIA STANDARD WASKADA NO. 16-13

Ideal development of Bakken and Lyleton formations. The section in Waskada is almost identical in character to that found in the type Bakken section. Upper, Middle, and Lower Bakken are all well developed. In such areas the top of the Lyleton is easily picked, at the base of the lower black shale, but in the north and east parts of the map area, such as the Max Lake area (Fig. 4), the Lower Bakken shale is not present, and the Lyleton top is very difficult to pick.

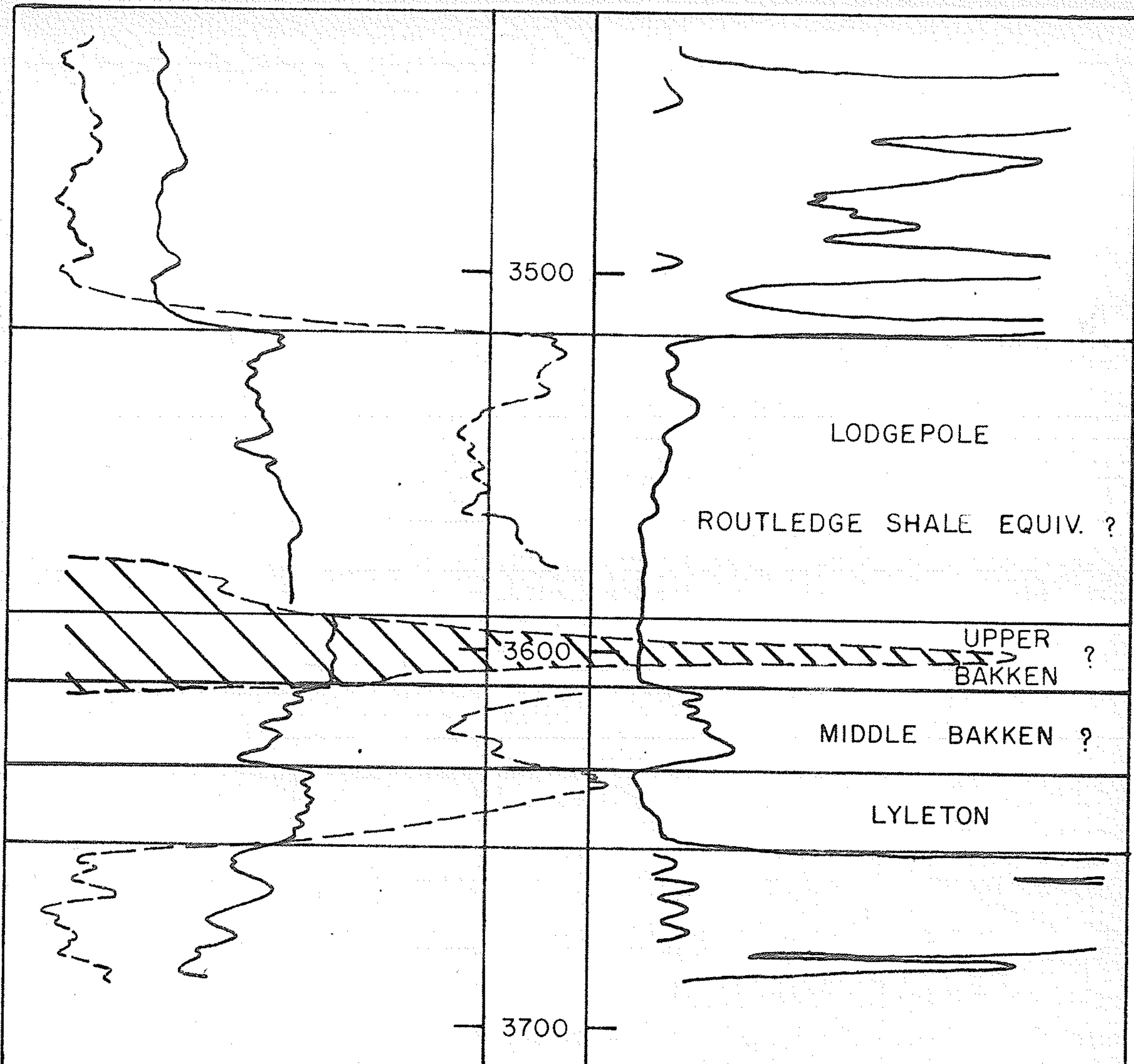


Fig. 4. ROYALITE TRIAD ET AL MAX LAKE NO. I.

Correlation not yet certain. Lower Lodgepole apparently shows development of black shale and siltstone facies very similar to the Bakken. The Middle Bakken siltstone is very well developed, but the Lower Bakken black shale is missing. The Lyleton, as picked by the writer, is very thin, and consists of green dolomitic shale in the upper part, grading to red dolomitic shale in the lower part. It is conformable with the Middle Bakken. It is possible that the green shale underlying the Middle Bakken is Lower Bakken equivalent.

When fully developed, the Bakken consists of three members, an upper black shale, a middle siltstone, and a lower black shale. However, the lower shale, may be missing and, as a result, the Lyleton may be directly overlain by either the Middle or Lower Bakken.

None of the members of the Bakken are easily distinguished from the Lyleton on electric logs. The Middle Bakken shows, slightly higher resistivity and S. P. values, and the black shales tend to show slightly lower S. P. and resistivity values than the Lyleton. The top of the Lyleton is usually marked by a small peak on the resistivity, and on the S. P. curve, but it is not usually well developed.

The Lyleton top is easily picked on the radioactivity logs, where the Lyleton is overlain by black shale, as the black shale shows extremely high values, several times greater than for the Lyleton (Fig. 4). However, where Lyleton is in contact with Middle Bakken (Fig. 3), the top is more difficult to pick. The radioactivity value for the Middle Bakken is less than for the Lyleton.

Tops for the Lyleton are best determined from cored sections, but, even with the core, it is frequently difficult to pick the contact, as there is no sharp break in lithology. Well cuttings are sometimes useful, but the units are thin, and the quality of the well cuttings is usually not good enough to pick the contacts accurately.

Lithology -- There was, unfortunately, no Lyleton core available at the time this study was undertaken. Several cores had been taken in what was at that time believed to be Lyleton, but, on the basis of more recent correlations, most of these cores were actually taken in the Lower or Middle Bakken. Subsequent to the study, two completely cored sections of the Lyleton were examined by the author, but no detailed petrographic examination was made. These wells were the California Standard Scallion 5-11, (5-11-11-26 WPM), and the Royalite - Triad Max Lake No. 1 (4-36-1-21 WPM).

The lithology of the Lyleton is quite similar in both wells, consisting of a greenish-grey dolomitic shale at the top, grading downward into a red argillaceous dolomite, or dolomitic shale. There is no appreciable amount of silt or sand present in the Lyleton of either of the cores.

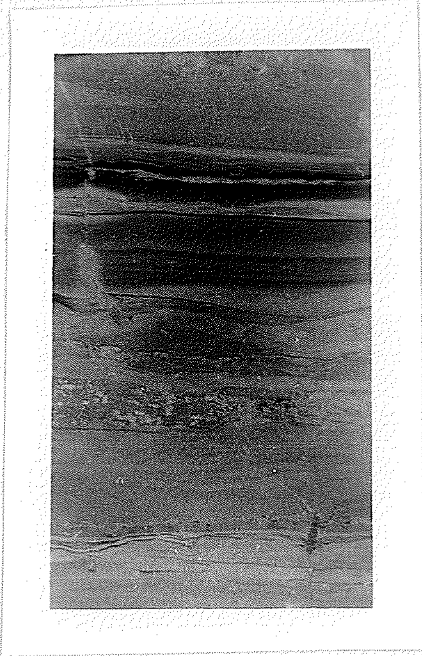
Several zones of very coarse breccia are present in the Lyleton of the Scallion well. The breccia consists of large fragments of light grey dolomite in a dark grey shale matrix. A number of thin beds of grey dolomite are also present in the Scallion well, but none were observed in the Max Lake well. Some minor anhydrite is present near the base of the Lyleton in the Max Lake well.

The Lyleton is generally massive, except for the breccia zones. Slickensides are common in some bands, and some bands also have a finely contorted to brecciated appearance. No good shaly cleavage is developed in any of the specimens examined. Cores from the Daly and Ewart wells (Fig. 5) show finely banded to cross-bedded crystalline dolomite with thin green shale interbands, but it is uncertain whether these samples are from the Lyleton or Middle Bakken.

Petrographic examination of red fragments of Lyleton from well cuttings indicated, in all cases, a dolomitic shale to argillaceous dolomite, with only a trace of fine silt-size quartz grains. In the more argillaceous bands, the dolomite commonly occurs as euhedral rhomb shaped crystals. The euhedral habit of the dolomite grains is characteristic of all specimens examined.

Binocular examination of well cuttings showed a few rounded, frosted, sand grains in the Lyleton interval, but these grains were always loose, and never seen directly associated with Lyleton lithology. The writer believes that they are primarily cavings from the overlying Middle Bakken. Some sand and silt may be present in the Lyleton, but are very minor in amount in comparison with the clastic content of the Amaranth.

The red coloration toward the base of the Lyleton



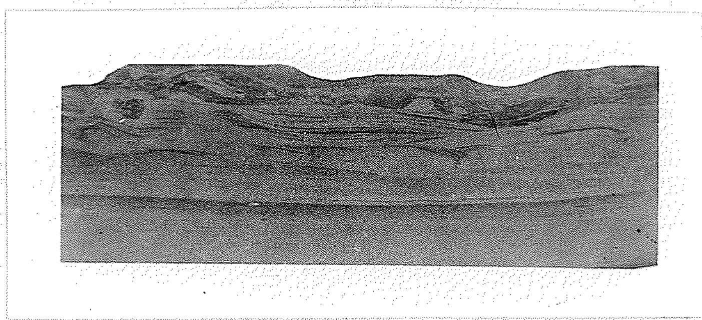


Fig. 5. Lyleton or Bakken ? Finely laminated or cross-bedded argillaceous dolomite and shale, interbanded red, green, and purplish red to gray. Correlation is uncertain in this area but specimens are from either uppermost Lyleton or Middle Bakken. Sample (A) from Calstan West Daly 8-29-10-28, at 2903', add sample (B) from Calstan Ewart Prov. 4-14-8-28 at 2907'. (X 1)

does not occur at the same stratigraphic position in all wells. The Lyleton top was originally picked by some workers at the first occurrence of red dolomitic shale, but this was found not to be a consistent marker horizon. The lower part of the Lyleton shows well developed red coloration in all wells examined, but may grade upward into green shale in some areas, as in the Scallion and Max Lake wells.

Nature of the Contacts -- Both the upper and lower contacts of the Lyleton appear to be conformable on the basis of the limited information available. In the cores examined the lower contact with the Nisku was sharp in the Scallion well, but did not show any evidence of brecciation or weathering of the Nisku prior to deposition of the Lyleton red beds. In the Max Lake well, the contact appeared to be conformable, and is somewhat gradational. The zones of breccia near the base of the Lyleton are probably local intraformational breccias, as the fragments are not lithologically similar to the underlying Nisku, and occur a considerable distance above the base of the unit. Some thin dolomite bands in the Lyleton are very similar to the dolomite fragments in the breccia zone, and are probably the source rocks of the breccia.

The upper contact of the Lyleton is conformable and gradational in all wells examined. The gradational nature make it difficult to pick the contact in many wells. In the Max Lake well, for example (Fig.3), the Mississippian limestones are underlain by a greenish grey siltstone. On the basis of electric log correlations, the thick black shale appears to be equivalent to the Lower Bakken. This would place the silt underlying the black shale in the Lyleton formation. The writer, however, does not believe that the stratigraphic relationships of the Bakken are well enough known to determine whether the silt is Bakken or upper Lyleton equivalent. Lithologically it would seem to be more similar to the Bakken.

(Note: More recent subsurface studies indicate that the upper shales and silstones in the Max Lake well are Lower Lodgepole, and probably equivalent to the Routledge shale. Thus the silt zone is Middle Bakken, and Lower Bakken black shale is missing as the writer had suggested.)

It was difficult to pick the Lyleton top in all cores and samples examined, and the writer believes that there is so much variation in thickness and lithology both laterally and vertically that, at best, only approximate contacts can be picked, until further subsurface information is available.

There was insufficient information, at the time of this study, to determine if there is any regional variation in lithology of the Lyleton in the map-area. There appears to be a slight increase in carbonate content to the west, as indicated by the dolomite bands in the Scallion well. To the west, in Saskatchewan, the Lyleton becomes increasingly evaporitic and calacreous, and grades into the Potlach evaporites of the Moosejaw Basin.

Isopach -- Possible error in determining the Lyleton top should be taken into account when considering the Lyleton isopach map (Plate 2). The map, however, shows a fairly uniform thickening of the Lyleton to the west, indicating that the tops picked by the writer are probably fairly consistent, though some of the irregularlities may be due to errors in picking the top. The thinning of the Lyleton is entirely depositional except for the narrow band peripheral to the erosional edge of the Mississippian where the Lyleton is truncated by erosion. The Lyleton attains a maximum thickness of one hundred and fifty feet in the map-area, and, in Manitoba, the section ranges from about twenty five feet to one hundred and twenty feet in thickness.

Plate 2

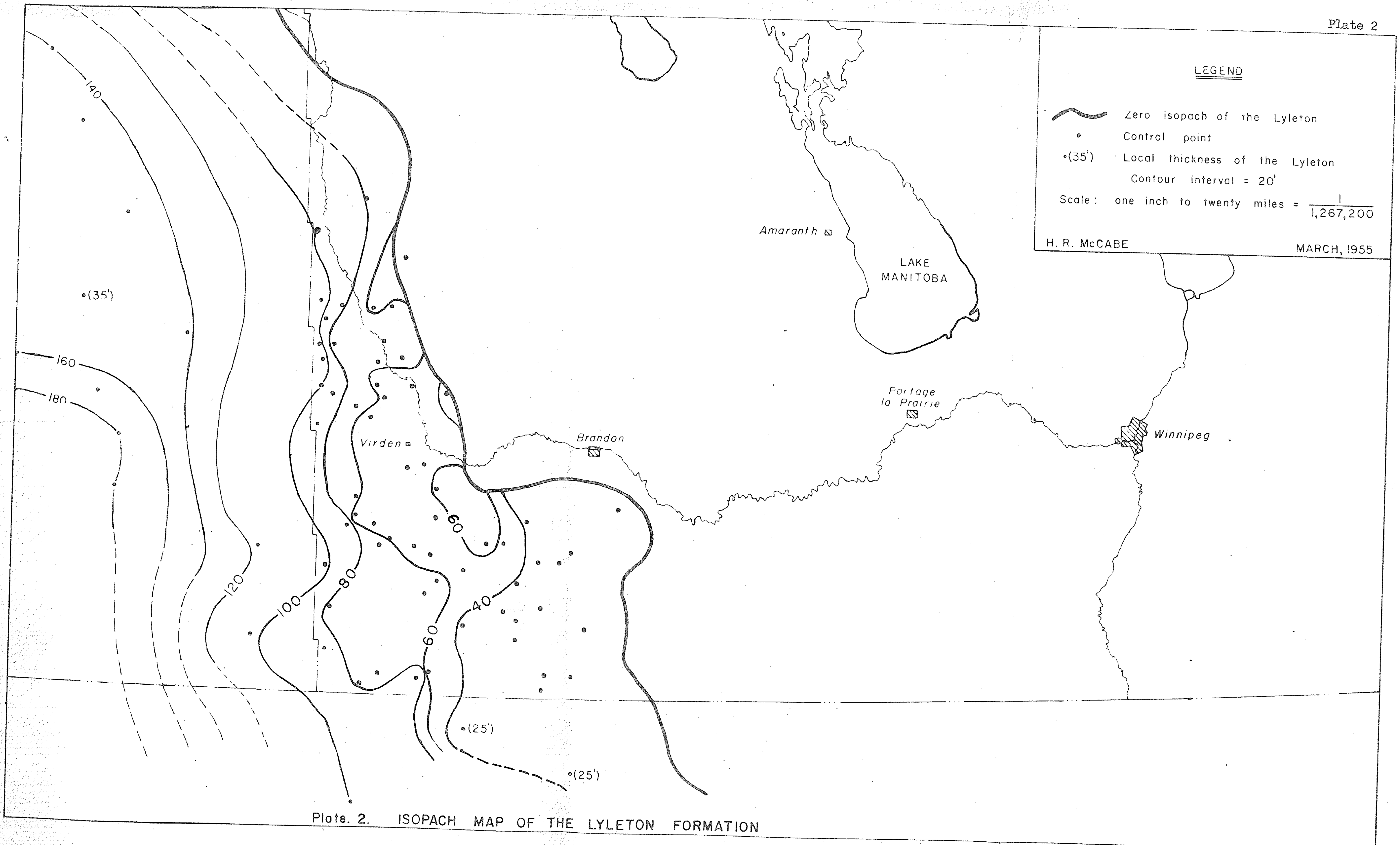


Plate. 2. ISOPACH MAP OF THE LYLETON FORMATION

CHAPTER III

DESCRIPTIVE STRATIGRAPHY OF THE LOWER AMARANTH

Definition -- As defined in this report, the Lower Amaranth is the basal red bed member of the Amaranth formation. It consists of the assemblage of red dolomitic sandstones, shales and siltstones overlying eroded Paleozoic strata, and underlying the evaporites and carbonates of the Middle and Upper Amaranth. The Lower Amaranth is not restricted to the area east of the limits of the Mississippian as suggested by Wickenden (1945), as it overlies eroded Mississippian throughout the entire southwestern part of the map-area.

Electric and Radioactivity Log Characteristics -- The Lower Amaranth is usually very sharply defined by its characteristics on the resistivity and gamma ray logs, as shown in Fig. 6. Lower Amaranth beds show a very low resistivity in marked contrast to the extremely high resistivity values shown by the overlying Amaranth evaporites and the underlying Paleozoic carbonates. The gamma ray curve shows a very high radioactivity level for the Lower Amaranth, in contrast to the low radioactivity of the adjacent strata.

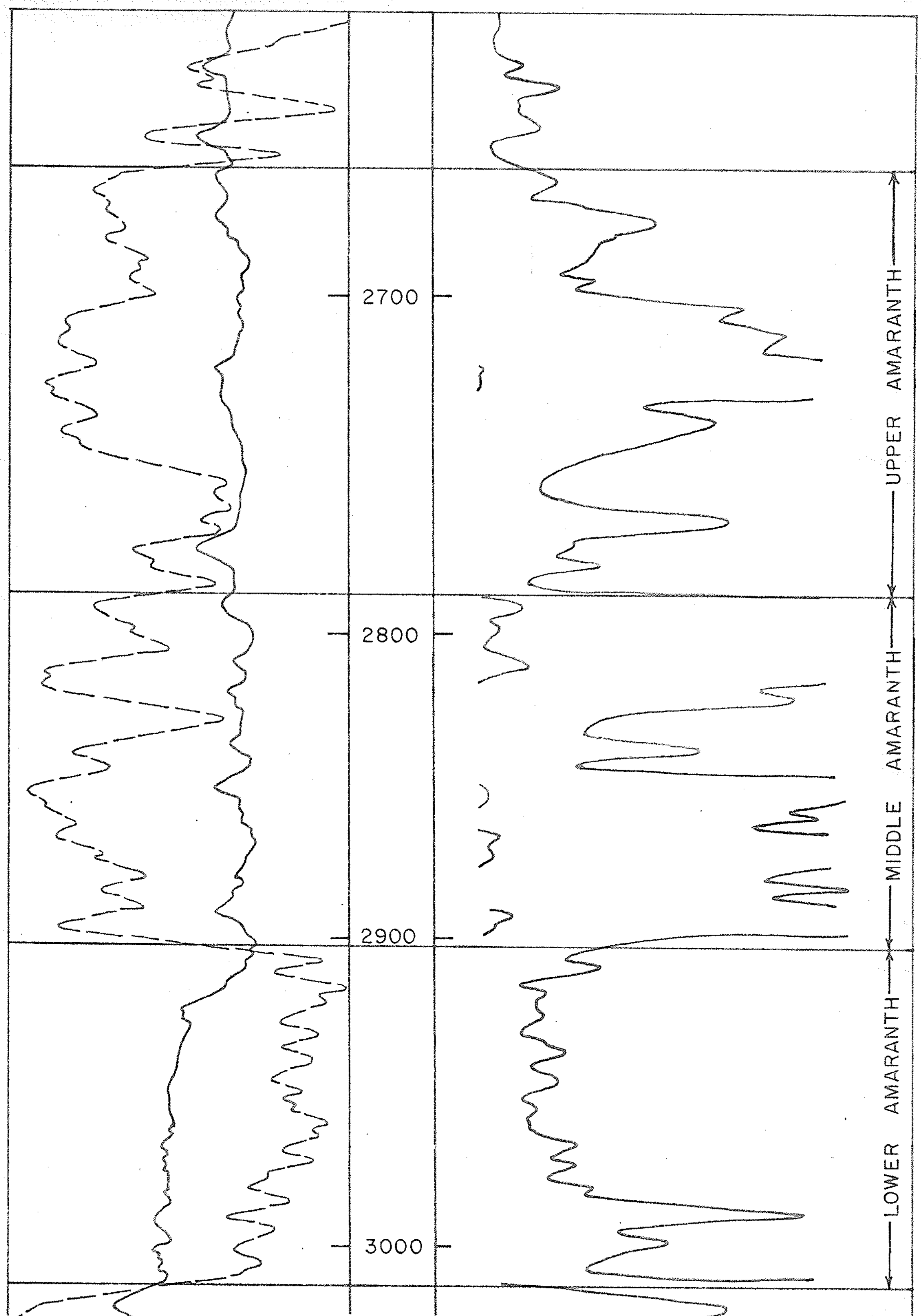


Fig. 6.
CALIFORNIA STANDARD WASKADA NO. 16-13

The upper contact of the Lower Amaranth is always well defined, and where the Amaranth is underlain by Paleozoic carbonates as in the Waskada well (Fig. 6) the lower contact is also usually well defined. However, in certain areas where the red beds are underlain by argillaceous strata such as the Charles or Lyleton, the lower contact is poorly defined due to the similarilty in electric, radioactivity, and lithologic characteristics.

Lithology -- The type section of the Amaranth is defined by Wickenden from the Neepawa and Manitou wells, however, as the term Amaranth was originally suggested for the red beds and evaporites at Amaranth, the recent diamond drill core taken near the town of Amaranth is probably the best section from which to define the Lower Amaranth. A detailed description of the Amaranth test hole and other selected wells is given in Appendix II.

The Lower Amaranth, at Amaranth, is essentially one lithologic unit with only minor variations in lithology. It shows no visible bedding or prominent structures of any sort, though it has the overall characteristics of a graded bed. The uppermost part of the unit is a dolomitic shale that grades downward into a silty dolomitic shale, and finally to a sandy, silty, dolomitic shale to siltstone at the base. There is a thin breccia zone at the Devonian contact. Unfortunately, the core was obtained after the writer had completed the laboratory study, and no detailed petrographic examination was made.

The color is a uniform to slightly mottled moderate brownish-red throughout. There is no interbanding with green shales near the contact with the overlying anhydrite, although, in some areas, Ower and others have reported interbanded green shales near the top of the Lower Amaranth. There are, however, a few small patches of greenish grey shale near the top, due to local reduction of the red pigment.

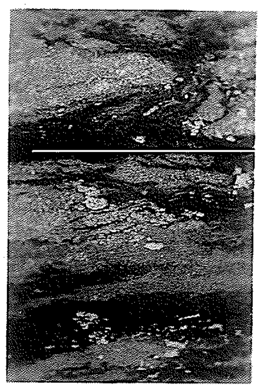
In the Amaranth area, where the upper part of the Amaranth has been subjected to erosion, the upper twenty feet of the Lower Amaranth red beds are profusely shot with veinlets of secondary fibrous gypsum.

The lithology at Amaranth corresponds closely with the type sections described by Wickenden, although both the Manitou and Neepawa sections are sandier towards the base, and several dolomite bands are present in the Neepawa well. To the southwest, where Mississippian strata are present, the lithology of the Lower Amaranth is also similar to the Amaranth, Neepawa, and Manitou sections. There were, however, no complete cored sections of the Lower Amaranth in this area, and well cuttings were very poor. The cores that were available are basal Lower Amaranth, and consist of medium brownish-red to reddish-brown silty shales and argillaceous siltstones, with minor sandstone lenses. Anhydrite is also quite abundant. Most sections show an increase in the content of coarse sand and silt towards the base of the unit, as at Amaranth, although this increase is quite erratic, and some sandstone is found even in the upper part of the unit. It is, however, much more abundant near the base.

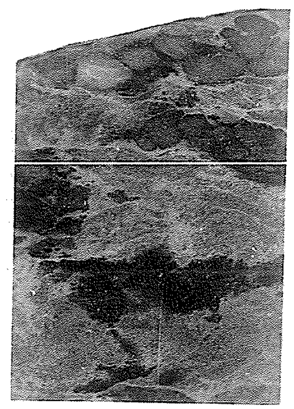
In general the grain size of the Lower Amaranth increases towards the southwest. In the extreme southwest of the Province the red beds are primarily a sandy siltstone, in contrast to the predominantly shale section at Amaranth. Farther to the southwest, in the Blanche Thompson well in North Dakota, the section becomes a medium-grained sandstone. To the west, in Saskatchewan, the Amaranth or lower Watrous also contains more coarse clastic material than in Manitoba (D. R. Francis, personal communication).

In Manitoba, the anhydrite content of the Lower Amaranth also seems to increase to the southwest.

Most Lower Amaranth cores show very striking sedimentary structures, as shown in Figs. 7-14. The most charac-



(A)



(B)

Fig. 7. Lower Amaranth. Typical irregular, mottled, swirled or pseudo-breccia structure characteristic of much of the Lower Amaranth siltstone. The darker bands and patches are more argillaceous , and the lighter patches generally more dolomitic, anhydritic, and sandy. The white patches in (A) are inclusions or fragments of clean, crystalline anhydrite. Both samples are from the California Standard Waskada 9-13-1-26 well at approximately 3010 feet. (X 1)

teristic structure is the extremely irregular swirled or contorted pattern shown on the polished surfaces (Fig. 7). In a few specimens small sections of the core showed faint remnants of cross-bedding, and slickensides are quite common in the more shaly bands.

Irregular to well-rounded patches and aggregates of anhydrite, scattered throughout the section, are common in the Lower Amaranth, especially towards the base of the unit (Figs. 9-13). The anhydrite is coarsely crystalline, and does not contain any clastic material such as clay or silt (Fig. 20). The anhydrite also occurs as thin uniform bands that in places show structures similar to mud cracks (Fig. 8). In many places anhydrite constitutes the cement or matrix in the sandy bands (Fig. 17).

The most characteristic feature of the Lower Amaranth is the abundance of large, extremely well rounded, spherical sand grains, with frosted to very highly pitted surfaces (Figs. 13-18). These sand grains are the most distinctive characteristic of the Lower Amaranth, but they are also found in other stratigraphic units. They occur in the Middle Bakken, in the Jurassic shales, and possibly also in the Lyleton formation. The rounding, frosting, and pitting, however, is not as pronounced as in the Lower Amaranth, nor is the sand as abundant in any of the other units, with the exception of the Bakken sand.

The sand grains found in the well cuttings from the Lyleton interval may actually have been cavings from the Bakken sand.

Petrography of the Amaranth Sand -- The composition of the Amaranth sand is extremely varied, but, in most specimens, feldspar grains constitute from 15 to 35 per cent of the coarse clastic fraction and quartz or chert the remainder. The feldspar content may be even higher, because the unaltered and untwinned feldspar is easily mistaken for quartz in the grain count. The Amaranth sand is consequently classified as an arkose or a feldspathic sandstone depending on the amount of feldspar present.

The silt size fraction is too fine grained to permit petrographic distinction between quartz and feldspar grains, but, even in this size range, numerous particles of finely twinned albite could be seen, and it is probable that feldspar is as common in the silt-size fraction as in the sand.

The types of feldspar found in the coarse sand fraction of the Lower Amaranth are microcline, orthoclase, and sodic plagioclase. They occur as monominerallic grains or as granitic aggregates of feldspar and quartz. Potash feldspars are the most abundant, forming sixty to seventy per cent of the identifiable grains. The remainder consists of plagioclase of albite to andesine composition. A few grains of microperthite, and micrographic or myrmekitic granite were found.

The feldspar grains show all stages of alteration, from clear unaltered feldspar to grains that are completely altered to kaolinite and sericite and are barely recognizable as original feldspar.

The percentage of feldspar in the Amaranth sand appears to show an increase to the southwest, although the data were insufficient to establish a definite trend. The sand in the Manitou and Neepawa wells shows a much lower feldspar content, approximately 5 per cent, than in wells to the southwest such as Waskada, in which approximately 30 per cent of the sand is feldspar. Only one detailed grain count was made for the Waskada well and it is possible that the percentage of feldspar recorded is unusually high in this particular sample. However, visual comparison with several other wells in the southwestern part of the map area indicated comparable feldspar percentages.

The quartz grains are of two distinct types, one showing sharp extinction, and the other a marked undulatory or strained extinction under crossed nicols. The former frequently contain extremely fine, oriented, needle-like inclusions, possibly of rutile. The latter often are aggregates of quartz grains that are tightly sutured and interlocked. There are also large grains consisting of aggregates of very fine, sutured quartz grains that are either fine-grained quartzite, or coarse chert fragments.

Fine plates of muscovite and biotite are frequently very abundant along bedding planes, especially in the southwest part of the area where the grain size is coarser. The mica gives a poorly developed, irregular, shaly parting to the rock.

Minor amounts of garnet, magnetite, quartzite, igneous rock fragments, and limestone fragments are also present in the coarse sand size fraction. Also, fine to coarse irregularly rounded patches of clean crystalline anhydrite are present, most of which show a sharp contact with the adjacent matrix.

Matrix -- The composition of the matrix of the sand and silt is very difficult to determine petrographically. It is red to light brownish grey, and is usually extremely finely crystalline to cryptocrystalline. From a study of the insoluble residues (Table 3) carbonate, primarily dolomite, is the principal constituent of the matrix. The carbonate content of the matrix varies from about 20 per cent to 80 per cent, with large variations present within the same well, and between different wells. The average carbonate content is about 25 per cent. (footnote).

(Note: The apparent per cent of carbonate in the samples, as determined from the Table of Insoluble Residues, may be slightly high. Some of the loss in weight is actually due to solution of anhydrite rather than carbonate, but the writer believes that in most samples the loss in weight is essentially a measure of the carbonate content of the specimen.)

In a few specimens of siltstone the matrix is a clean, finely crystalline dolomite containing no argillaceous material. The carbonate matrix appears to show slight replacement of a few of the quartz grains in some of the specimens.

The rest of the matrix consists of extremely fine-grained quartz, clay, and red hematite pigment. X-ray studies showed that the clay mineral is illite, and that quartz is very abundant in the clay-size fraction. No other clay minerals, feldspar, or hematite was indicated in X-ray photographs of the fine insoluble residues of the Amaranth specimens. The hematite was lost during the insoluble residue analysis, as all red color disappeared during the acid treatment.

The results of the insoluble residue analyses (Table 3) are too variable to indicate any regional trends, or to be of any use in correlation. The most notable feature is the rapid variation in composition in some wells, even for closely spaced two foot samples from the same cored section. In other wells, however, the percentage of insoluble residue varies as little as one per cent between samples from the same well.

Nature of the Contacts -- The writer was able to observe the contact between the Lower and Middle Amaranth in only one well, the Amaranth test hole. In this well the section grades from massive gypsum to red dolomitic shale profusely shot with stringers

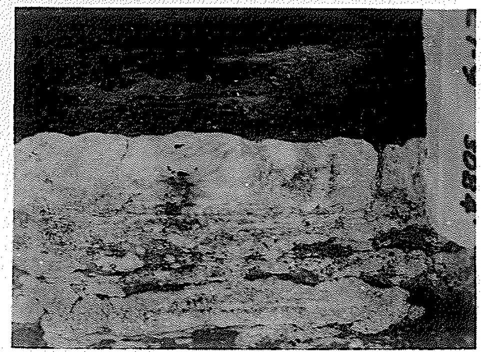


Fig. 8. Lower Amaranth. Thin band of anhydrite in dark reddish siltstone. The upper surface of the bed shows what appear to be slight erosional and desiccation structures. Calstan Tilston 5-32-5-29 at 3084 feet. (X 1)

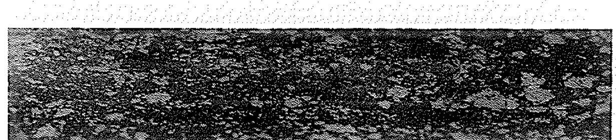


Fig. 9. Lower Amaranth. Fine fragments or inclusions of anhydrite irregularly scattered throughout reddish brown siltstone. Calstan Tilston 5-32-5-29 at 3089 feet. (X 1)

Fig. 10. Lower Amaranth. Lens of irregularly rounded inclusions or fragments of clean crystalline anhydrite in siltstone. Can. Devonian Creekside Mitchell #1 at 2346 feet. (X 1)

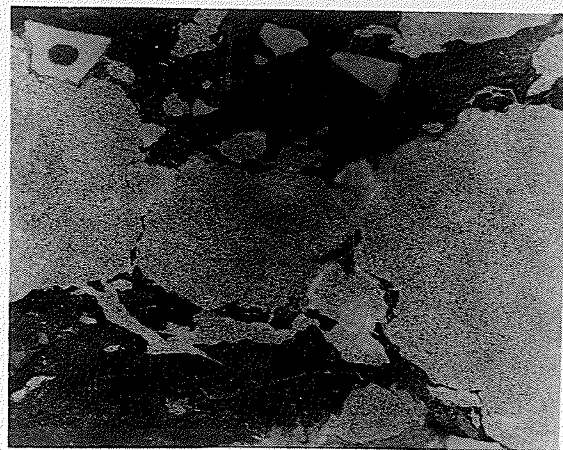


Fig. 11. Anhydrite inclusions in basal Lower Amaranth siltstone. Also several angular fragments of dense white chert, one of which shows a dark brown center. The white color appears to be due to weathering of originally brown chert fragments. Calstan Hargrave Prov. 15-16-11-27 at 2508 feet. (X 1)

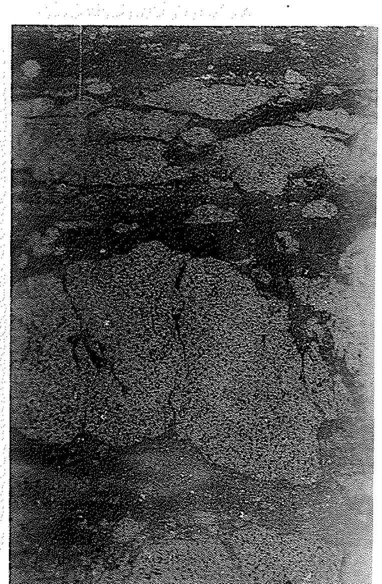


Fig. 12. Lower Amaranth. Characteristic irregular to rounded inclusions or fragments of crystalline anhydrite in dark reddish brown siltstone. The anhydrite fragments tend to occur in bands and lenses. Calstan Tilston Prov. 5-32-5-29 well at 3095 feet. (X 1)

Fig. 13. Sandy band in Lower Amaranth showing the association of coarse, well rounded and frosted sand grains, rounded fragments of anhydrite, and angular fragments of dolomite. The band shows considerable inclination to the core. Pascar Hunt 10-9-1-27 well at 3208 feet. (X 1)

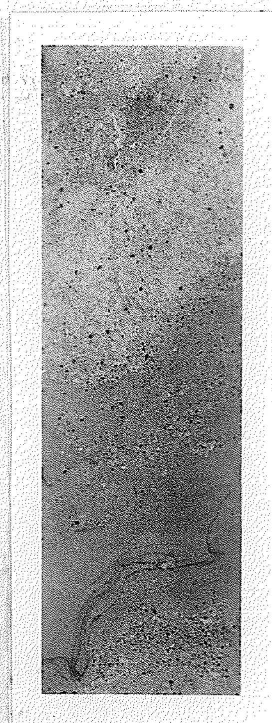
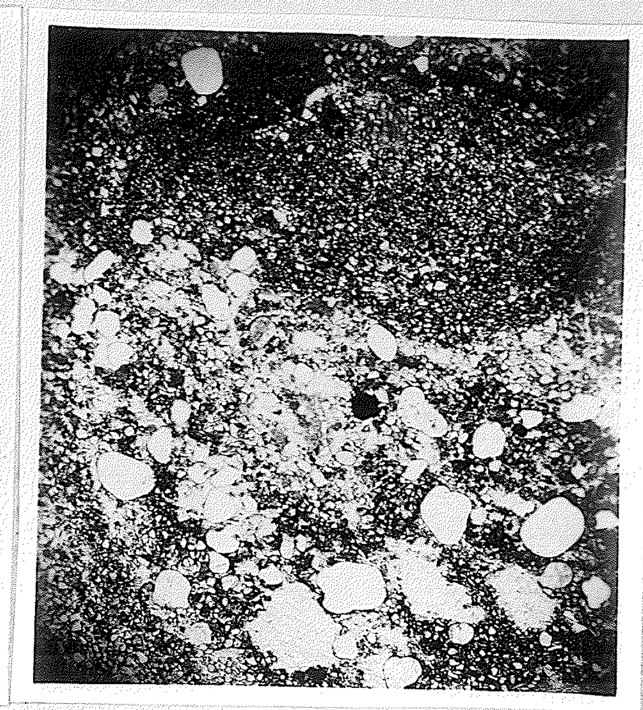
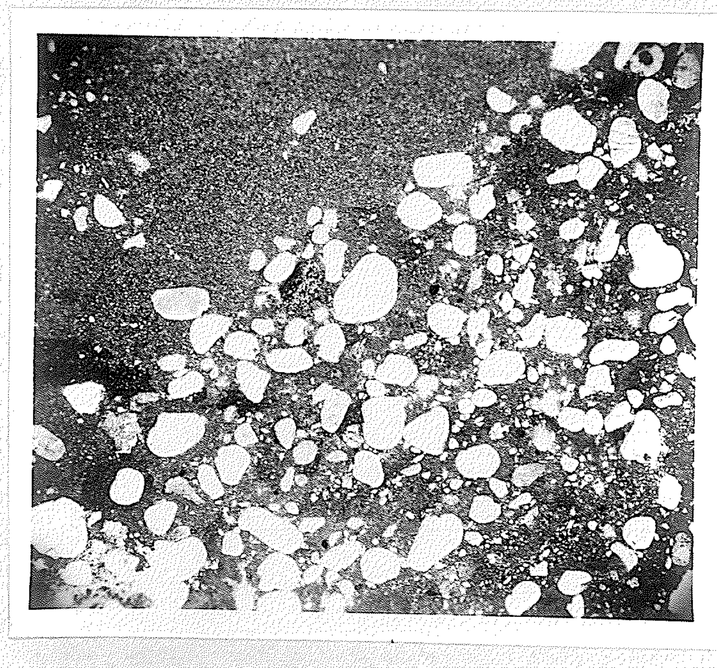


Fig. 14. Sandy band in Lower Amaranth. Upper lighter colored part is anhydritic. Lower part is darker colored, finer grained, dolomitic, and shows pronounced slump or flowage structure. Calstan Waskada 9-13-1-26 well at 3013 feet. (X 1)



(A) (B)



(C)

Fig. 15, Characteristic sandy bands in the Lower Amaranth showing the good rounding and sphericity of the larger sand grains, and the poor sorting. Sample (A) from Calstan Creekside Mitchell 10-32-9-27 ; (B) from Calstan Waskada 9-13-1-26 ; (C) from Calstan Ewart Prov. 4-14-8-28. (X 15, plain light)

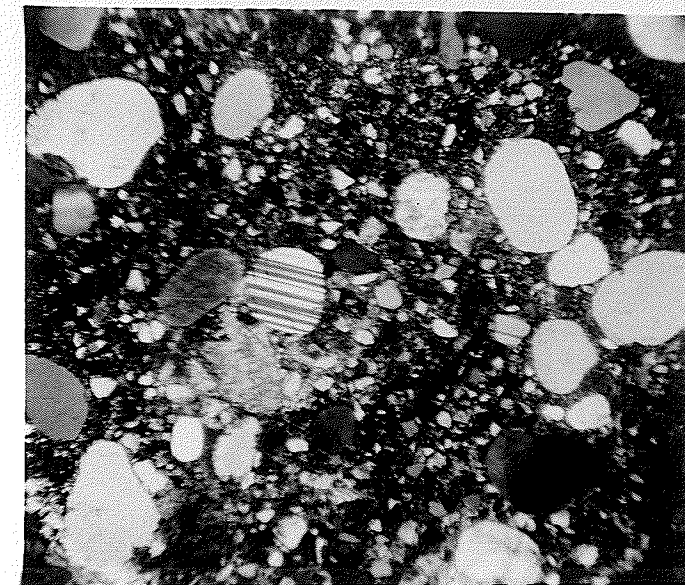


Fig. 16 Sandy band in Lower Amaranth siltstone. The perfectly fresh, well rounded grain in the center is Albite-Oligoclase feldspar. To the left is an equally well rounded feldspar grain that has been almost completely weathered to Kaolinite etc. Calstan Tilston Prov. 5-32-5-29 . (X 20, crossed nicols)

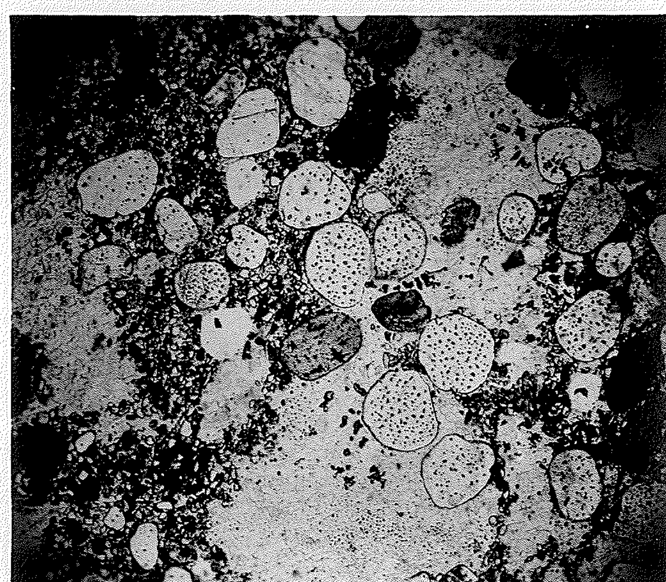


Fig. 17. Sandy Lower Amaranth with large well rounded quartz, feldspar, and chert grains. Sand and silt are floating in a matrix of clean crystalline anhydrite. Pascar Hunt 10-9-1-27 . (X 15, plain light)

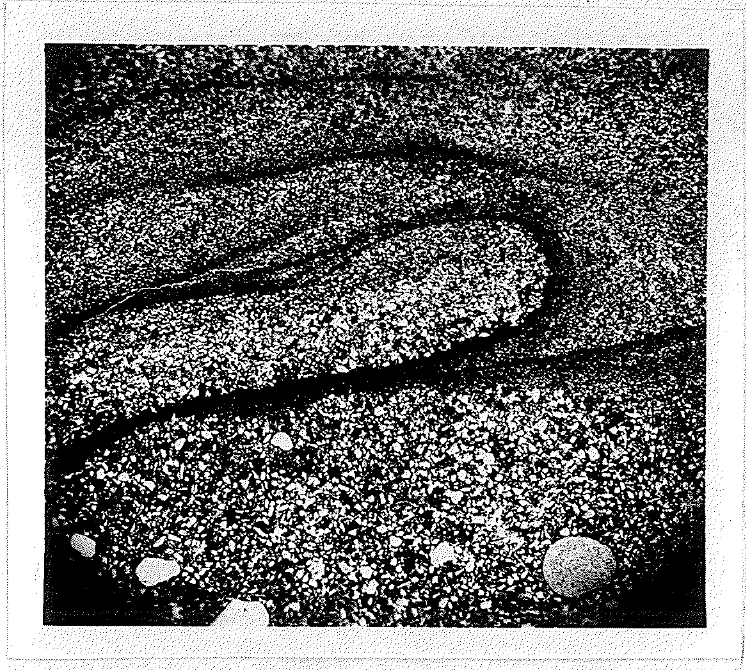


Fig. 18. Lower Amarath siltstone showing pronounced slumping or flowage structure. The dark laminations are argillaceous material. Note the variation in grain size from fine silt to medium sand. Grain in bottom right is weathered feldspar. Calstan Waskada 9-13-1-26. (X 15, plain light)

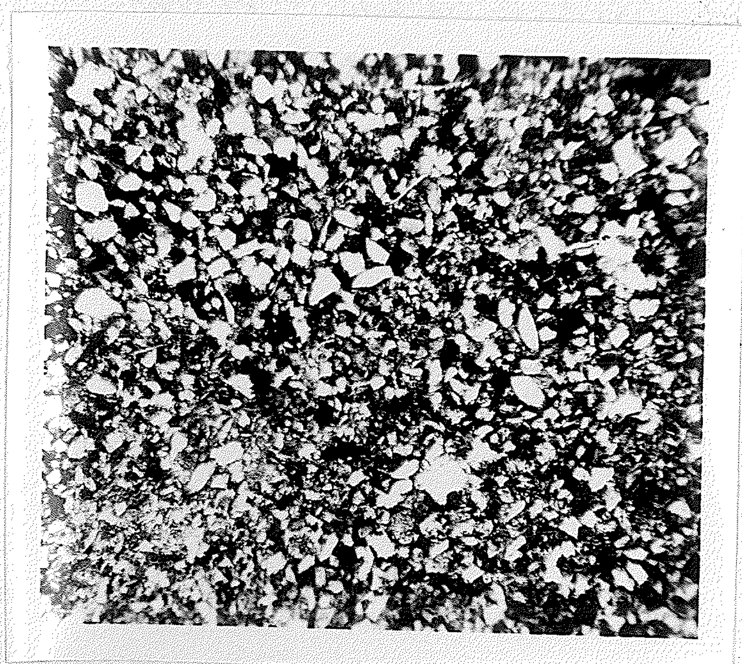
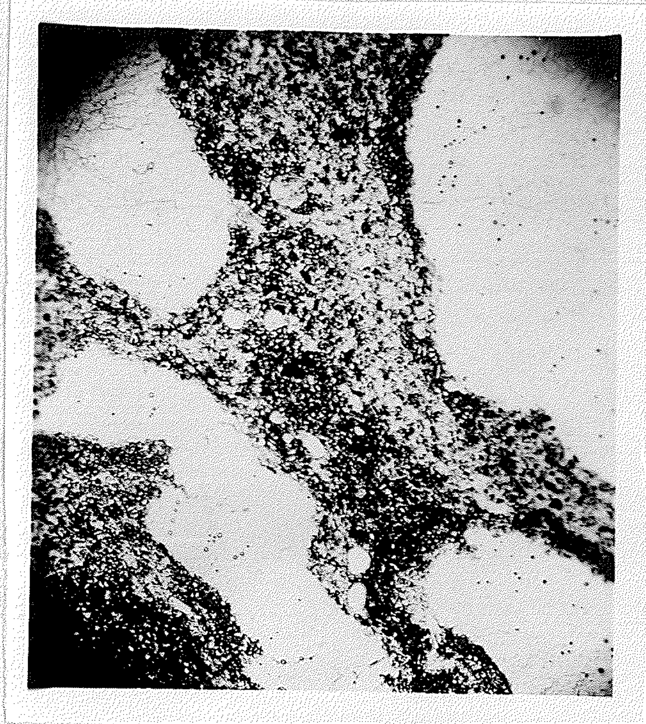


Fig. 19. Lower Amarahth siltstone. The grain shape varies from angular to subrounded, with some small grains showing very good rounding. The thin lath-like flakes are Muscovite. The matrix is argillaceous and dolomitic. Calstan Waskada 9-13-1-26. (X 60, plain light)



(A)

(B)

(C)

Fig. 20. Lower Amaranth. Inclusions or fragments of clean crystalline anhydrite in coarse siltstone matrix. The siltstone is quite clean with little associated argillaceous material. The cement of the siltstone is predominantly anhydrite, with some dolomite. Note the fine banding of dark minerals and argillaceous material in (C). Samples (A) and (C) ffom Calstan Waskada 9-13-1-26 ; (B) from Calstan Creekside Mitchell 10-32-9-27. (X 15, plain light)

Fig. 21. Breccia band near the base of the Lower Amaranth. Light gray angular fragments of dolomite in a light greenish-gray to reddish matrix of dolomitic argillaceous siltstone. Sample from Canadian Devonian Creekside Mitchell 16-32-9-27 well at 2370 feet. (X 1)

Fig. 22. Breccia band near the base of the Lower Amaranth with large splintery fragments of light gray to mottled dense dolomite up to 3" in diameter, and abundant large rounded fragments of anhydrite. Sample from Calstan Hargrave Prov. 15-16-11-27 well at 2372 feet. (X 1)

of fibrous secondary gypsum, and finally to massive red shale with no gypsum. The gradational zone of red shale shot with gypsum is probably a secondary feature associated with the hydration of the anhydrite by surface solutions. Electric logs indicate that the contact between the Lower and Middle Amaranth in other wells is sharp, though there may be a slight interbanding of red shale and anhydrite at the contact.

The basal contact of the Lower Amaranth may be sharp with little or no evidence of unconformity, as in the Pascar Hunt well and the Amaranth test hole, where there are few breccia fragments of the underlying strata in the Amaranth. The contact may also be gradational through a breccia or detrital zone consisting primarily of fragments of the underlying strata in a matrix of siltstone and anhydrite, grading to limestone or dolomite shot with anhydrite and siltstone along fractures. The Miniota well shows such a detrital zone at the base of the Lower Amaranth.

<u>Distribution and Thickness</u> -- The distribution and thickness of the Lower Amaranth are shown on the isopach map (Plate 3). The distribution pattern of the Lower Amaranth is similar to that of the overlying Jurassic strata, except that it extends somewhat farther to the northwest before it is truncated by erosion. There is also a north-south trending area along the Saskatchewan

TABLE 3

INSOLUBLE RESIDUE ANALYSES *

Well	Cored Interval	Weight per cent
Calstan Daly 15-18	(2512-2517)	
Sample No. 1		45
" 2		47
Calstan West Daly 8-29	(2658-2668)	
Sample No. 1		43
" 2		38
" 3		38
" 4		47
" 5		52
(Sample probably from Middle Bakken)		
Calstan Eward Province 4-14	(2899-2909)	
Sample No. 1		57
" 2		61
" 3		36
" 4		41
" 5		37
" 6		35
" 8		24
" 9		68
" 10		48
" 11		26
(Sample probably from Middle Bakken)		

* Note: Most of the samples originally believed to be Lyleton have subsequently been proved to be Middle Bakken, but they are nevertheless included in the above table.

Sample numbers run from top to bottom, and are evenly spaced over the cored interval.

Well		Cored Interval	Weight per cent
Calstan Cruickshank 14-4		(2720-2727)	
	Sample No. 1		53
	" 2		47
	" 3		42
	" 4		43
	" 5		44
	" 6		50
	" 7		51
	(Upper samples are probably from the Middle Bakken, but the bottom two samples are either Lower Bakken or Upper Lyleton)		
Calstan Woodnorth Province 5-18		(2662-2672)	
	Sample No. 1		36
	" 2		44
	" 3		49
	" 4		42
	(Sample probably from Middle Bakken)		
Pascar Hunt #1		(3200-3213)	
	Sample No. 1		71
	" 2		72
	" 3		72
	" 4		70
	" 5		74
	" 6		75
	(Samples from Lower Amaranth)		
Calstan Ewart Province 4-14		(2527-2535)	
	Sample No. 1		66
	" 2		71
	" 3		66
	" 4		48
	" 5		42
	" 6		16
	" 7		24
	(Samples 1 - 5 are Lower Amaranth. Samples 6 and 7 are Upper Mississippian)		

Well	Cored Interval	Weight per cent
Calstan Hargrave (Province) 15-16	(2492-2510)	
Sample No. 1		20
" 2		8
" 3		2
" 4		41
" 5		8
" 6		28
" 7		34
" 8		24
" 9		35
" 10		30

(Samples from Upper or Middle Amaranth, and detrital zone. Only minor red shales at base. Pronounced breccia throughout)

Calstan Elkhorn 7-8A		
Sample No. 1		66
" 2		92
" 3		72

(Samples from Lower Amaranth)

Amaranth Gypsum Mine, Amaranth Manitoba		
Sample No. 1		84

(Sample from Lower Amaranth)

Canadian Devonian Creekside Mitchell #1	(2311-2377)	
Sample No. 1		77
2		78
3		78
4		78

(Samples from Lower Amaranth)

Calstan Waskada 16-13	(2993-3026)	
Sample No. 1		22
" 2		24

(Samples from Lower Amaranth)

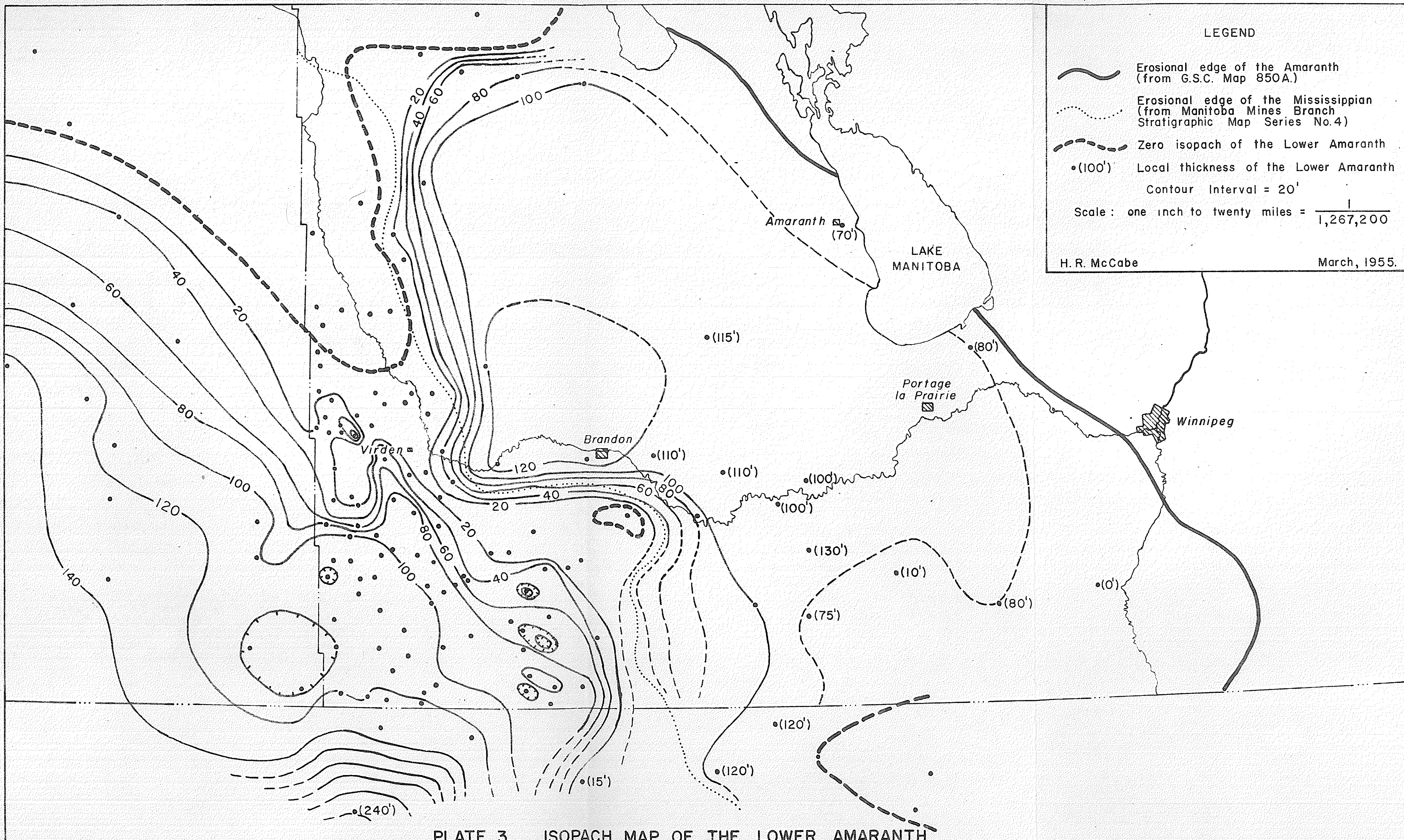


PLATE 3. ISOPACH MAP OF THE LOWER AMARANTH

border, in the northern part of the map area, where Lower Amaranth beds are thin or absent. Throughout the rest of the area, the Lower Amaranth ranges in thickness from a few feet up to one hundred and fifty feet. The thickness is surprisingly uniform, considering that the Lower Amaranth was deposited on a profound pre-Jurassic erosion surface.

There are several areas where the Lower Amaranth is exceptionally thin. One is a broad poorly defined area near Wawanesa that appears to extend to the north-west, trending approximately parallel to the erosional edge of the Mississippian strata. Along this trend the Lower Amaranth is generally less than twenty feet thick, and is absent in some wells. This trend cannot be traced accurately to the southeast owing to the lack of subsurface control.

The second unusually thin area trends north-south through the Daly - Virden district. It constitutes the southern extension of the previously mentioned area along the Saskatchewan border where the Lower Amaranth is missing.

The Lower Amaranth thins towards the north in the Grandview wells, and the entire Jurassic section pinches out between Grandview and the Swan River area, where Cretaceous strata rest directly on Devonian rocks. The writer noticed a few pieces of red siltstone, containing rounded frosted sand grains, overlying the Devonian in the Swan River well, indicating that a few feet of Lower Amaranth may be present in this area.

No attempt was made to indicate on the isopach map the thickness of the Lower Amaranth in the area of the California Standard Hartney 16-33 well, because it may be either absent, or more than eight hundred feet thick, depending on the interpretation of the subsurface data.

Hartney appears to be well within the area of Mississippian suboutcrop, as far as can be determined from the latest subsurface data, and a thickness of about four hundred feet of Mississippian strata would be expected in this well on the basis of the isopach trends shown by Zaborniak (1955). Mississippian strata, however, are completely missing in this well, as are approximately four hundred feet of upper Devonian beds, and in their place is seven to eight hundred feet of variegated green and grey shale, with minor sandstone and limestone, resting directly on Devonian rocks. These shales have no lithologic similarity to the Lower Amaranth red beds, but their possible stratigraphic relationships to the Amaranth will be discussed in a later section.

Paleogeology - The Lower Amaranth lies unconformably on a predominantly limestone sequence, which ranges in age from middle Mississippian Charles in extreme southwestern Manitoba to middle Devonian at the northeastern erosional edge of the Amaranth (Plate 4). Beds of progressively younger age occur to the southwest, towards the center of the Williston Basin, where an essentially complete stratigraphic section from Devonian to Jurassic is present.

Comparison of the Lithology of the Lower Amaranth With Underlying Strata -- The Charles formation, from its occurrence in the McKague No. 1 well, is essentially a red bed unit consisting of red to maroon shales, dolomitic shales, and massive bedded anhydrite, in contrast to the red silstone, sandstones and minor, patchy anhydrite of the Lower Amaranth. The two are quite easily distinguished in core and samples, but are quite difficult to distinguish in electric logs. The Charles in most wells shows a higher resistivity value than does the Lower Amaranth because of its higher content of anhydrite.(Plate 6).

The Charles is of very limited occurrence in Manitoba, and is found only in the extreme southwestern part of the province. The erosional edge of the Charles is likely to be irregular, as it is believed to be in part a lateral or facies equivalent of the Mission Canyon formation. The Charles - Mission Canyon contact thus appears to move up and down in the section, and consequently the erosional edge of the Charles cannot be easily predicted.

Structures present in the Mississippian strata also cause irregularities in the erosional edge and in the thickness of the Charles, as in the Waskada area. These irregularities could cause correlation difficulties with the Charles and the Lower Amaranth where the two are in erosional contact.

Mission Canyon beds are primarily light buff, oolitic, fossiliferous-fragmental limestones, and with the exception of the thin shale and anhydrite band of the MC-2 could not be confused with the red shale and siltstone of the Lower Amaranth. The MC-2 is lithologically somewhat similar to the Lower Amaranth, but lacks the characteristic red coloration and high silt content.

The Lodgepole formation is primarily a mottled reddish to purplish-grey, argillaceous, cherty limestone, containing varying amounts of crinoidal debris. It contains several beds of red argillaceous limestone that are similar in appearance to the Lower Amaranth and have been incorrectly identified as Amaranth in areas where the two are in erosional contact. The Lodgepole red beds, however, are much more calcareous and much less silty than the Lower Amaranth, and do not contain appreciable anhydrite.

The Mississippian Bakken formation consists of three members, an upper black shale, a middle gray siltstone or sandstone, and a lower black shale. The silt member frequently contains abundant rounded, frosted sand grains, as does the Lower Amaranth, but it can usually be distinguished from the Amaranth by its grey color, and by the presence of pyrite.

The Lower Amaranth directly overlies the Lyleton red beds in a narrow band peripheral to the erosional edge of the Mississippian. This is well shown in the Imperial Birtle well, and the Dome Algar well. In the latter, a nearly complete section of Lyleton is present directly below the Amaranth, but, in the Birtle well, all but a few feet of the Lyleton have been eroded. It is not possible to distinguish between the Lower Amaranth and the Lyleton in electric logs, but the approximate contact can be picked from the well cuttings in both wells. The most important characteristic in distinguishing between the two units is the lack of sand and silt in the Lyleton formation. (For a detailed comparison of the Lower Amaranth and Lyleton see page 68).

The oldest strata known to be overlain by the Amaranth are Devonian limestones and dolostones, with minor shales and evaporites. There are at least two well defined beds of red argillaceous limestone in the Devonian, the 'First Red', and the 'Second Red', that could be confused with the Lower Amaranth where the two are in erosional contact. The Devonian red beds, however, are argillaceous limestones in contrast to the dolomitic siltstones and sandstones of the Lower Amaranth. A reddish, argillaceous limestone occurs a few feet below the Amaranth-Devonian contact in the Amaranth test hole, and may correspond to one of the Devonian red beds.

The Amaranth may have rested on Ordovician or Silurian strata to the east, but subsequent erosion has reduced the areal extent of the Lower Amaranth to its present limits. The Amaranth undoubtedly extended much farther to the east at one time, as the Lower Amaranth isopach shows only a slight thinning in this direction. The anhydrite deposit at Gypsumville may possibly be an outlier of Amaranth lying directly on Silurian strata.

The paleogeographic map (Plate 4) shows the formations directly underlying the Amaranth and indicates those containing red beds that might be confused with the Lower Amaranth where the two are in contact.

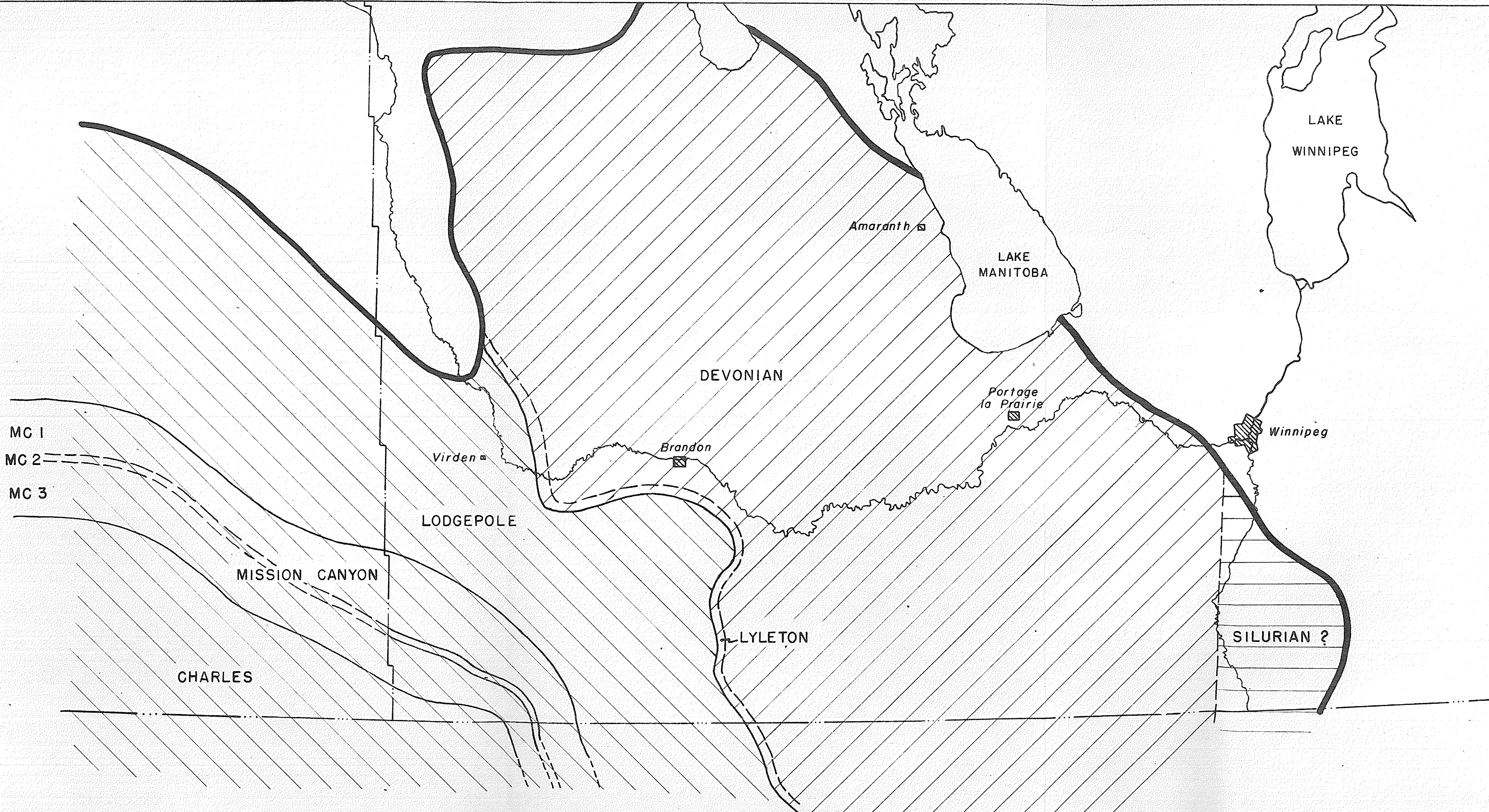


PLATE 4. PALEOGEOLOGIC MAP OF THE LOWER AMARANTH

CHAPTER IV

COMPARISON OF THE AMARANTH AND LYLETON FORMATIONS

Both the Lower Amaranth and the Lyleton are predominantly red beds, but they differ considerably in lithology, and can generally be distinguished in well cuttings and core samples.

The Lower Amaranth contains abundant silt and medium to coarse, well rounded, frosted, and pitted sand grains, especially towards the base of the unit. In contrast the Lyleton consists of shale and argillaceous dolomite, and contains no appreciable sand or silt in any of the specimens examined.

The Lyleton is considerably more dolomitic in general than the Lower Amaranth. The Lyleton grades to an only slightly argillaceous dolomite in some bands, whereas the Lower Amaranth, in almost all samples analysed, consists predominantly of sand, silt, shale, and anhydrite.

The Lyleton contains more green colored sediments towards the top than does the Lower Amaranth. All cored sections of Lyleton examined by the writer show some green shale overlying the red beds, but none of the Lower Amaranth cores show significant amounts of green shale, although Ower (1953) and others have reported minor green shales in the upper part of the Lower

Amaranth. The green shale in the upper Lyleton is commonly pyritic.

No anhydrite was found in any of the Lyleton samples examined by the writer, whereas the Lower Amaranth contains abundant associated anhydrite in the southwest part of the map area. The anhydrite content of the Lower Amaranth however decreases towards the northeast, and no anhydrite was found in the lower part of the red bed section in the Amaranth test hole.

No breccia zone is present at the base of the Lyleton, but the basal Lower Amaranth in many places shows a very pronounced breccia zone, as in the Creekside Mitchell and Hargrave Province wells (Figs. 21 and 22). However, in some wells such as Pascar Hunt there is no breccia zone at the base of the Amaranth.

The position in sequence of the Lyleton and Lower Amaranth is also very different. In the map area both are underlain by dolomitic or anhydritic limestones, but the Lyleton is overlain by the black shales and siltstones of the Bakken formation, whereas the Lower Amaranth is always overlain by the upper Amaranth evaporites and carbonates, except along the erosional edge.

Though the Lyleton and the Lower Amaranth are quite easily distinguished from each other by the above characteristics, the Lower Amaranth does show some phases that are almost identical to the Lyleton. The upper part of the Lower Amaranth is predominantly a red shale with little associated sand or silt, and is lithologically similar to the Lyleton, though usually less dolomitic. Also, the sand and silt content of the Lower Amaranth apparently decreases in the northeastern part of the map area, as in the Amaranth test hole, where the sand and silt content is relatively low and the lithology of the Lower Amaranth differs little from the typical Lyleton lithology, though even here it is less dolomitic, and more silty.

CHAPTER V

INTERPRETATIVE STRATIGRAPHY OF THE LYLETON FORMATION

Environment of Deposition -- Very little information is available for use in determining the conditions under which the Lyleton was deposited, therefore the following interpretations are only tentative.

The writer believes that the Lyleton in Manitoba is probably primarily of shallow water marine origin, though the lower part of the unit may be in part non-marine terrestrial, especially towards the east. The cores from the Scallion and Max Lake wells, and cuttings from other wells show that the carbonate content is considerably greater in the western part of the map area, and the dolomite bands in the Scallion core are definite indication that at least a part of the Lyleton is of marine origin.

The shallow water nature of the sediments is shown by the presence of the coarse intraformational breccias, as in the Scallion core, and possibly by the very finely banded and cross-bedded shales and dolomites found in the West Daly 8-29, (8-29-10-28 WPM), and Ewart Province 4-14, (4-14-8-28 WPM), wells (Fig. 5). No similar finely laminated structures were observed in either the Scallion or Max Lake wells, and it is possible that the Daly and Ewart cores are actually from the Bakken rather than from the Lyleton.

The red coloration of the sediments in the lower part of the Lyleton indicates deposition in an oxidizing environment, or at least removal before deposition of all reducing material such as organic matter. Preservation of red coloration in such a thin uniform sheet of sediments would most easily occur in a terrestrial or transitional environment, and some of the red shales especially in the eastern part of the area may have been deposited under such conditions, but where the Lyleton is in part a dolomite or highly dolomitic shale, as in the western part of the map area, it must be of marine origin.

The gradation from red shales and dolomites at the base, to purplish-grey, drab, and greenish grey sediments with considerable pyrite in the upper part of the Lyleton indicates a change in conditions from shallow marine oxidizing to probably marine, partly restricted or stagnant reducing conditions. The color is probably controlled by the local environment, which would account for the erratic occurrence of the red-green shale contact in the section.

The presence of considerable pyrite in the green shale is somewhat unusual, as pyrite is most commonly associated with black shales rich in organic matter (Pettijohn, 1949). The appearance of the green pyritic shale in the section appears to foreshadow the widespread establishment of marine euxinic conditions at the start of Mississippian time, during which the highly radioactive, conodont-bearing black shales of the Bakken or Exshaw were deposited.

Source Area - The increase in argillaceous content to the east indicates an eastern source for the clastic material (as suggested by Baillie, 1953), and the fairly pronounced thinning of the Lyleton to the east suggests that the depositional edge of the Lyleton was not too far east of the present erosional edge.

The scarcity of coarse clastic material, such as sand or silt indicates a low lying source area for the Lyleton sediments. The rocks of the source area were probably sedimentary, in contrast to the predominantly igneous-metamorphic source area for the Lower Amaranth sediments (page 93). The writer does not believe that the Precambrian Shield was exposed to the east during Lyleton time, however, the sand and silt zones of the Bakken indicate an influx of coarse clastic detritus immediately after Lyleton time. The writer was not able to do any detailed work to determine the nature or the source area of these sands and silts.

It is possible that the relationships between the Lyleton and the Bakken may be more complicated than at present believed, and the two formations may bear in part a lateral or facies relationship to each other, however, the writer was not able to find any direct evidence to support this idea. Because of the pronounced variation in lithology in the Bakken-Lyleton interval, and the difficulty in picking the contact between the two units, except in local areas where the Bakken shows the ideal three fold development, it may eventually become necessary to re-define the units or to combine both units into one stratigraphic unit of variable lithology.

Recent Mississippian correlations indicate that the lower part of the Lodgepole formation develops, in some areas such as Routledge and Max Lake, a black shale and siltstone facies very similar to the black shales of the Bakken. As the Bakken and Lyleton are also closely related, with no erosional break between them, it seems possible that the upper Lyleton could also show a partial facies relationship with the Bakken.

The Middle Bakken siltstone is underlain either by 'Lower Bakken' black shale, 'Lyleton' red shale, or 'Lyleton' green pyritic shale, and it may be that all three are facies equivalents of the same unit. The Middle and Upper Bakken, however, seem to be separate, relatively continuous stratigraphic units.

Lyleton time was apparently one of tectonic quiesence, as the Lyleton isopach shows no pronounced variations aside from the more or less uniform thickening to the west.

CHAPTER VI

AGE AND CORRELATION OF THE LYLETON FORMATION

The Lyleton formation is easily correlated throughout the southwestern part of the map-area by electric and radioactivity logs, and by well samples. It consists of an assemblage of green and red shales, dolomitic shales, and dolomite occurring between known Mississippian and known Devonian strata. The Lyleton occurs only in the area where it has been protected from pre-Amaranth erosion by Mississippian strata, with the exception of a thin peripheral band immediately to the east of the erosional edge of the Mississippian where the Lyleton is directly overlain by the Lower Amaranth beds.

The Lyleton occupies a stratigraphic position similar to the red beds of the Three Forks formation in Montana, and has been correlated with this unit by some workers. However, according to W. M. Laird (personal communication) the Three Forks is only partially equivalent to the Lyleton. The Three Forks is also the facies equivalent of some of the Upper Devonian carbonates that underlie the Lyleton in the Williston Basin area, and consequently the Lyleton is equivalent only to the upper part of the Three Forks formation. The latter is believed to be Upper Devonian in age.

No fossils have yet been recovered from the Lyleton formation, so its age cannot be determined directly. However, recent paleontologic evidence indicates that the Lower Bakken contains a fauna showing both Mississippian and Devonian affinities, and is either latest Devonian or earliest Mississippian in age. The underlying Lyleton formation would hence probably be Upper Devonian in age as indicated by Baillie (1953).

To the south and west of the map-area, the Lyleton shows pronounced lateral facies changes. Carbonates are abundant to the south in North Dakota, and grade to predominantly anhydrite in the Potlach evaporite basin in southern Saskatchewan (Baillie, 1953). These rapid lithologic changes make regional correlations extremely difficult.

The writer believes that the term Lyleton should be retained, at least in the map-area where the unit maintains essentially the same lithologic characteristics. To the south and west of the map-area, where the Lyleton equivalents show markedly different lithologic characteristics and thickness, different formational names such as the Potlach Evaporites, and the Three Forks should be applied, and an arbitrary cutoff made between the partially time equivalent but lithologically different units.

CHAPTER VII

INTERPRETATIVE STRATIGRAPHY OF THE LOWER AMARANTH

Isopach - The Amaranth formation was deposited on a profound pre-Amaranth erosion surface. At the northeastern limit of the Amaranth outcrop a thousand feet or more of Devonian and Mississippian limestone have probably been eroded, but a near peneplain surface must have been developed because the thin Lower Amaranth deposits are almost everywhere present on this erosion surface. The maximum local relief could not have exceeded about three hundred feet, and throughout most of the area was very much less, as shown by the thin and fairly uniform Lower Amaranth isopach (Plate 3).

One factor that may possibly result in emphasizing the variation in thickness of the Lower Amaranth is that most oil wells are drilled on seismic anomalies. The principal horizon that is studied in seismic exploration is the top of the Mississippian strata, that is, the pre-Amaranth erosion surface. Consequently any 'anomalies' on this erosion surface will be associated with 'anomalies' in the Lower Amaranth red beds which were deposited on this surface. Thus it is to be expected that information obtained from such oil wells will not be truly representative of the Lower Amaranth, either for isopach or lithologic data.

The thickness of the Lower Amaranth may be even more uniform than suggested in the isopach map.

The variations in thickness shown in the isopach map are probably a result of topographic irregularities on the pre-Amaranth erosion surface controlled by one or more of the following factors:

(1) Normal erosion features.

(2) Stratigraphically controlled erosional features.

(3) Structurally or tectonically controlled topographic features.

(4) Local environment of deposition.

Normal Erosional Features -- Such features include stream valleys and monadnocks. In areas where the strata underlying the Lower Amaranth are lithologically uniform and show no unusual structural features, the Lower Amaranth shows a very uniform thickness with little indication of stream valleys or monadnocks on the erosion surface.

Stratigraphically Controlled Erosional Features -- Such features include cuestas and hogbacks caused by differences in resistance to weathering of adjacent strata.

The thinning of the Lower Amaranth in a broad area parallel to the erosional edge of the Mississippian strata seems to have been stratigraphically controlled. The Mississippian edge probably existed as a broad, low, ridge-like area on the pre-Amaranth erosion surface. Lower Amaranth sediments are very thin or absent over this ridge, and in a few areas such as Wawanesa the relief of the ridge was sufficient to prevent deposition of the Middle and Upper Amaranth as well. In general, however, the upper Amaranth evaporites and carbonates are continuous across this ridge. As the Amaranth is missing at Wawanesa and attains a thickness of approximately 300 feet immediately to the northeast of this area (Plate 6) the maximum relief across this ridge must have been at least 300 feet.

This ridge-like feature is probably an erosional escarpment or cuesta. It is asymmetrical as the red beds thin gradually towards erosional edge of the Mississippian, and thicken rapidly to a normal 100 to 150 feet immediately outside of the area of Mississippian rocks. The asymmetry is probably due to undercutting and erosion of the underlying, weakly resistant Bakken and Lyleton formations.

Structurally or Tectonically Controlled Topographic Features -- The structure of the underlying strata was an important factor in controlling the thickness of the Lower Amaranth, especially in the Daly-Virden area which is located on a north-south trending complex anticlinal structure along which the Mississippian strata show considerable thinning, as shown by the Mississippian isopach map (Zaborniak, 1955). The area must have existed as a topographic ridge on the pre-Amaranth erosion surface during Amaranth time, as Lower Amaranth beds are thin to absent.

The dating of the Daly structure is quite difficult. The writer believes that the structure is possibly a composite of tectonism during Mississippian time, and later Amaranth or immediately pre-Amaranth folding.

According to Fleming (personal communication) the erosional surface of the Mississippian is approximately parallel to the crinoidal marker horizon in the Mississippian. If the Daly structure had existed prior to erosion, the Mississippian strata overlying the marker horizon should show erosional thinning but they do not. Therefore, the folding must have taken place subsequent to the major part of the pre-Amaranth erosion and is probably of Lower Amaranth or immediately pre-Lower Amaranth age. Also, if the folding had taken place before the period of pre-Amaranth erosion, the erosion would have destroyed or at least greatly reduced the topographic expression of the structure, and a normal thickness of Lower Amaranth red beds would be present in the Daly area.

The thinning of the Mississippian strata in the Daly area, and the abundance of crinoidal limestone indicate the possibility of mild, relatively positive tectonism of this area during Mississippian time, in relation to more negative tendancies of the surrounding areas.

A detailed study of more recent data, especially of the structure contours of the overlying strata will be necessary before the structure can be more accurately dated.

The area north of Daly, along the Saskatchewan border, where no Lower Amaranth sediments at all are present (Plate 3) is probably the northward extension of the Daly anticlinal structure.

Several other small areas such as Tilston, Waskada, Pierson, and Whitewater show a slight thinning of the Lower Amaranth over structures in the underlying Mississippian strata. These, however, are very minor structural domes in comparison to the Daly anticline.

Local Environment of Deposition -- Variation in the environment of deposition may also have caused minor variations in the thickness of the Lower Amaranth but was probably important primarily in determining the size, sorting, and composition of the sediments deposited in a given area.

By the end of Lower Amaranth time most of the irregularities on the Pre-Amaranth erosion surface had been filled in, with the exception of the area north of Daly, and a few isolated areas such as Wawanesa, which persisted as topographic highs throughout Amaranth time, and did not undergo sedimentation until later Jurassic (Reston) time.

The Hartney Structure -- One of the most puzzling features of the subsurface stratigraphy of Manitoba is the stratigraphic succession on the Hartney structure. The California Standard Hartney 16-33 well was drilled on a pronounced seismic anomaly, and passed directly from Jurassic shale into Devonian limestone in an area where a four to five hundred foot thickness of Mississippian strata was expected on the basis of Mississippian isopach trends. The pre-Cretaceous shales overlying the Devonian limestones are about 900 feet thicker than usual in this well, and some upper Devonian beds as well as the entire Mississippian section are missing. No beds lithologically similar to the Amaranth are present.

Seismic evidence indicates that the anomaly is confined to an oval-shaped area less than one township in extent, as shown by Zaborniak (1955), and that the Mississippian strata show a slight dip away from the Hartney area on all sides. The nearby East Hartney well shows what appears to be a normal sedimentary sequence (Plate 6).

The sediments in the Hartney hole are primarily grey to green variegated shale with minor sandstone, anhydrite, and limestone. The most unusual feature of the sediments is the extreme contortion, folding, and brecciation. Inclinations of forty to fifty degrees are common, slickensides are abundant, and much of the section appears to have undergone much disturbance and brecciation. The Calstan Hartney 16-33 (16-33-5-24 WPM), Royalite-Triad East Hartney #1 (2-27-5-24 WPM), and Madison Lauder 1-19 (1-19-5-24 WMP) wells are all associated with the Hartney structure though the latter two are peripheral to the structure.

In the Hartney well, the only one with any cored section, the brecciation and folding appear to be confined to the stratigraphic interval from Lower Cretaceous to Lower Devonian. The Upper Cretaceous strata correlate well across the Hartney structure, and show no sign of deformation in any of the cored sections. The basal Cretaceous Swan River Sandstone also correlated across the structure, but cores in this interval indicate some minor disturbance, which may be either tectonic (faulting), or depositional (slumping). The sediments below the Cretaceous, and above the Ashern cannot be correlated across the structure, as is shown in the cross-section A-A_1, Plate 6. No correlation lines were shown in the cross-section for those wells in the Hartney area.

There is definite evidence of faulting in the Lauder well as the lower part of the Lyleton and upper part of the Nisku are repeated, at least once and possibly three times, as shown in Plate 6. The thickness of the first repeated section is approximately 60', indicating that if the beds are assumed to be originally flat lying, the displacement along the first fault is at least 60', and since beds are repeated the faulting is of the reverse type. The Bakken formation in the East Hartney well also appears to show slight faulting and repetition. In the more or less uniform carbonates of the Mississippian and Devonian it is impossible to pick out any faulting from the electric logs, but the lack of correlation between nearby wells, and the brecciated appearance and minor faulting shown in the cores indicate that the carbonate units are also probably faulted.

The structure and associated faulting appear to die out at depth, as the Ashern formation correlates very well from Hartney to East Hartney. In the cross section (Plate 6) the two logs have been 'hung' from the Fish Scale zone, and excellent marker horizon at the base of the Upper Cretaceous. (Some section has been deleted from both wells due to the lack of space, but the Ashern formation does actually correlate as shown, because the same amount of section was deleted from both wells). Even the Ashern does not show quite the same electric log characteristics in both wells, as would be expected for such nearby locations, so the Ashern may also be involved in the deformation but to a much lesser degree than the overlying strata. It is possible that the decrease in deformation towards the base of the Devonian is only apparent, and is due to the structure being inclined to the direction of the bore hole, however, from the limited information available, the deformation appears to be confined to the stratigraphic interval from Lower Cretaceous to Lower Devonian.

A number of unpublished ideas have been proposed to explain the Hartney Hole. These ideas fall into two types, erosional, and tectonic. The most prevalent explanation at the present time is probably that the Hartney well was drilled near the erosional edge of the Mississippian, and happened to hit an old river canyon in the Mississippian escarpment. This interpretation is shown in the location of the edge of the Mississippian strata in Ower's report (1953), and also in Sproule's map (1954), where the erosional edge of the Mississippian is drawn through the Hartney well.

The writer does not believe that this idea is correct. More recent subsurface data give no indication that Hartney is near the erosional edge of the Mississippian strata, and no other wells have penetrated any similar canyon. Seismic evidence indicates that the Hartney structure is confined to a limited area as indicated by Zaborniak (1955), and is not a linear, channel-like feature. Also, the writer believes that, because the pre-Amaranth surface was reduced to a near peneplain, the entire area must have been close to erosion base level, and under such conditions a nine hundred foot deep river channel could not possibly have been formed. The channel theory does not explain the complex structures shown by the sediments in the Hartney well.

It has also been suggested that the Hartney structure is a solution phenomenon, a buried karst or solution cave, but, if the area was at erosion base level as the writer believes, such a karst topography could not have been developed, and moreover, solution phenomena could not account for the removal of the Bakken and Lyleton shaly formations. No other evidence for a buried karst topography has been found anywhere in the area.

Faulting has also been proposed to explain the Hartney structure. The writer, however, does not believe that faulting alone is a satisfactory explanation. The roughly circular shape, the localized nature of the phenomenon, and the apparent lack of disturbance of the overlying and underlying strata do not seem to support this idea. Faulting would, however, explain the complex structure and the brecciation in the Hartney section, and, as some faulting is definitely indicated in the Lauder well this idea cannot be completely rejected. Minor Paleozoic or Mesozoic faulting does occur in some areas of Manitoba such as the Virden-Roselea field, and Kammen-Kaye (1954) indicated considerable post-Mississippian faulting in southern Saskatchewan, but no faulting of such magnitude and complexity has previously been found in southwestern Manitoba.

The writer believes that the Hartney structure may be similar to the so-called crypto-volcanic structures that are found in the midwestern United States, as shown on the Tectonic Map of the United States. These structures are characterized by the following features:

(1) complex structure and faulting in the center of the structure, with the sediments showing steep dips. These structures apparently die out at depth.

(2) adjacent strata dip gently away from the structure on all sides.

(3) the structure is roughly circular to oval-shaped, and slightly asymmetrical.

(4) overlying strata may show considerable thickening over the structure.

The Hartney Structure shows all of the above characteristics. However, if it is a crypto-volcanic structure, the origin of the structure is still uncertain, as, according to current hypotheses, crypto-volcanic structures may have been formed either by meteor impact or by gaseous volcanic explosions, not accompanied by magmatism.

The age of the pre-Cretaceous shales in the Hartney 16-33 well is uncertain, and different ages can be proposed depending on the presumed age and origin of the structure. The writer believes that the sediments are probably Jurassic in age, and may be stratigraphically equivalent in part to the Lower Amaranth, even though there is no lithologic similarity. Due to the uncertainty in correlation the Amaranth section in the Hartney 16-33 well was disregarded in drawing up the Lower Amaranth isopach map.

Secondary Evaporite Zone Associated With The Pre-Amaranth Erosion Surface -- A twenty to fifty foot zone of tight anhydritic dolomite or dolomitic limestone is found in Mississippian rocks directly underlying the Lower Amaranth red beds. This unit is not a stratigraphic member of the Mississippian system, but is rather a zone of secondary alteration related to the unconformity surface and the overlying red beds and evaporites. It is probably the result of leaching of anhydrite from the red beds and deposition in the underlying porous Mississippian limestones, with some associated dolomitization and anhydritization of the limestones (Fig. 23). A dense, non-porous zone is thus formed at the erosion surface of the Mississippian, which acts as an impervious cap rock over some oil reservoirs.

This zone of anhydrite was mistakenly identified as Charles formation in some earlier stratigraphic work. In the area around Downey where Charles sediments are present, the Charles is very hard to distinguish from this alteration zone. The presence of shale and massive bedded anhydrite are character-

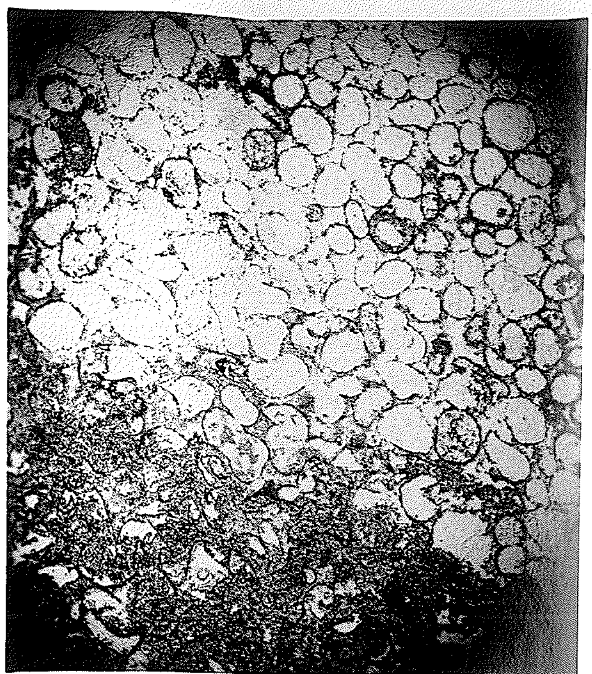


Fig. 23. Anhydritic - Dolomitic zone in the upper Mississippian immediately below the pre-Amaranth unconformity. Shows replacement of calcarenite by coarse crystalline anhydrite. The replaced oolites (?) are rimmed by fine crystalline dolomite. Calstan Waskada 9-13-1-26 at approximately 3030 feet. (X 15, plain light)

istic of Charles sediments.

No anhydritic zone was noted below the pre-Amaranth unconformity in the northeastern part of the area, where Lower Amaranth rests directly on Devonian strata. This is probably due to one or both of the following factors. First, the underlying Devonian limestones may be less porous than the Mississippian limestones, and hence less susceptible to anhydritization; and second, there is practically no anhydrite associated with the red beds in this area to cause anhydritization.

Lower Amaranth Detrital Zone -- The writer believes that the thickness of the detrital zone at the base of the Lower Amaranth is controlled primarily by the topography of the erosion surface, and indirectly by the structure of the underlying strata. There was insufficient data at the time of study to determine definitely, but it appears that those areas that were topographic and/or structural highs on the Lower Amaranth depositional surface, and which consequently show relatively thin Lower Amaranth deposits also show the thickest detrital zones.

In areas that were not topographic highs on the pre-Amaranth erosion surface, and which show a relatively thick Lower Amaranth section, the detrital zone is thin or absent. The secondary evaporitic zone in the Mississippian is also usually thinner in these areas.

Environment of Deposition -- The unusual conditions under which the Amaranth was deposited are shown by the complex nature of the sediments themselves. The red hematitic coloring matter indicates that the Lower Amaranth was deposited under oxodizing conditions, or at least that all reducing material such as organic matter was removed prior to deposition. Such conditions would most likely occur under a terrestrial rather than a marine environment.

The very irregular swirled or contorted structures shown in Fig. 7 with irregular patches of fine bedded and cross-bedded sediments, and slickensides, are also probably indicative of a terrestrial or transitional environment. Marine sediments would probably show more uniform bedding.

The nearly perfect roundness and sphericity of the Amaranth sand grains indicates that the sand has undergone much transport and abrasion, probably in an aeolian environment, as it is believed that sediments of very high roundness and sphericity are more common in aeolian sediments.

The pronounced frosting and pitting of most of the sand grains probably also indicates a terrestrial origin for the sand. The cause of these surface textures is not clearly known (Pettijohn, 1949), but they are commonly attributed to aeolian action. There is also a possibility that these textures are partially the result of surface solution or of incipient secondary enlargement of the grains. Petrographic examination showed what appeared to be slight replacement of the sand grains by the carbonate and anhydrite matrix in a few specimens, but such evidence was not conclusive.

The different modes of occurrence of anhydrite in the Lower Amaranth are probably the most diagnostic features in determining the environment of deposition. The anhydrite occurs as thin primary beds that sometimes show, on the upper surface, what appear to be desiccation structures (Fig. 8). Anhydrite also occurs as irregular to rounded patches scattered throughout the red siltstone and is especially abundant in the sandy bands (Figs. 13 & 17). The writer believes that this anhydrite is clastic in origin, and is probably derived from the breaking up of the primary anhydrite layers.

Such occurrences of anhydrite probably indicate periodic marine inundations of the area alternating with dry periods when evaporite pans were formed in the low lying areas. Some of these pans were subsequently broken up by wind and/or water action to form the clastic anhydrite. In the southwestern part of the area where the evaporites are more abundant, the periodic marine inundations were more prominent, and culminated in the complete inundation and establishment of marine evaporitic conditions of the Middle Amaranth.

The presence of evaporites, especially in the Middle Amaranth, probably indicates deposition in a warm arid environment, and the preservation of clastic anhydrite in the Lower Amaranth probably extreme aridity. The complete lack of any fossil remains also indicates extreme environmental conditions unfavorable for plant or animal life, or the preservation of any organic remains.

The presence of some perfectly clear unaltered feldspar grains, highly rounded and frosted by extremely long transport and abrasion, indicates that the environment of transportation and of deposition must have been such that chemical weathering was virtually absent, and under these conditions the feldspar was able to persist as an essentially stable mineral. Such conditions would probably occur in an arid aeolian environment, although there is little published information as to the stability of feldspar under different environmental conditions.

The presence of illite as the only clay mineral in the red beds is not diagnostic according to Grim (1951), who indicates that illite is universally present in all argillaceous sediments, especially in the older sediments, where it forms a diagenetic mineral.

<u>Nature and Location of the Source Area of the Lower Amaranth Sand</u> -- The Amaranth sand consists of quartz and feldspar

grains, rock fragments of granitic and metamorphic origin, and minor chert, garnet, carbonate, and quartzite grains. The source area for this material was primarily an igneous-metamorphic terrane with some associated cherty carbonates. There are no pre-Amaranth sediments in the map area that could have supplied arkosic detritus during Amaranth time, because the only formation containing any signifigant amount of clastic material is the Winnipeg formation, which does not contain appreciable feldspar (Genik, 1952).

The sandy strata of the post-Mission Canyon-pre-Amaranth sediments such as the Kibbey, Opeche, and Spearfish formations may possibly have been the source of the Amaranth sand. These strata are not present in the map area, and are confined to the central part of the Williston Basin. They have however been subjected to some degree of pre-Amaranth erosion, and could possibly have supplied the sand that occurs scattered throughout the Lower Amaranth. The Amaranth sand could thus be a second cycle sand which would account for the excellent rounding and sphericity. It is difficult however to see how a second cycle sand could retain such a high feldspar content with a considerable percentage of the feldspar still perfectly fresh.

The writer was not able to determine the mineralogy of the Kibbey and other sands, and it would be necessary to know the comparative petrography of the various sands to ascertain if they could have been the source of the arkosic sand of the Lower Amaranth.

Other possible source areas for the arkosic detrital material are the Precambrian shield to the east of the map-area, or an igneous-metamorphic terrane to the west in the Cordilleran orogenic belt.

The different degrees of alteration shown by the feldspar grains in the Amaranth sand can be explained by Krynine's theory as to the origin of red beds. The source area for arkosic red beds as described by Krynine (1949) is one of considerable relief, moderate rainfall, and warm climate, with resulting rapid erosion and strong chemical weathering. Material eroded from the interfluves will be highly weathered, and will contain abundant red hematitic material, whereas the material eroded from the stream channels will be comparatively fresh and unaltered.

Such conditions of erosion probably could not have been attained in the tectonically stable Precambrian area to the east, if the Precambrian was ever exposed in this area during Amaranth time. The only other possible source area would thus appear to be the Cordilleran orogenic belt to the west.

A western source area is also indicated by the increase in grain size of the clastic material in the Lower Amaranth to the west, and in Saskatchewan (D. R. Francis, personal communication). However, Francis (1954) also indicated that the Lower Amaranth equivalent, the lower part of the J-4-B, pinches out in western Saskatchewan, which suggests that the source area could not have been directly to the west. As the sand content also increases to the south, as shown by the Blanche Thompson well (North Dakota 31-160N-81W) the source area may have been to the southwest rather than to the west. Further detailed regional correlation of the Lower Amaranth will be necessary, however, to prove or disprove the Cordilleran source area suggested by the author.

Some quartz sand may possibly have been derived from an eastern Precambrian area, though evidence for such a source is very meagre. The Neepawa well located near the northeastern edge of the Amaranth shows an unusually well developed sandstone near the base (Wickenden, 1945), but it is a quartzose sandstone rather than an arkosic sandstone as to the west, which suggests an eastern source area for the Neepawa sand. However, the Amaranth test hole located even farther to the northwest, almost at the erosional edge of the Amaranth, shows a very low sand content with no indication of an eastern source area. The lack of sand in the Amaranth test hole might be due to local environmental control, as the Hart Green Wakely well, also located near the erosional edge of the Amaranth, shows a quite high sand content.

It is also possible that in the eastern part of the area, some of the quartz sand in the Amaranth was derived from erosion of the Winnipeg sandstone rather than from the Precambrian Shield.

Summary of the Paleogeography of the Amaranth Formation -- The writer believes that during Amaranth time the map-area was a very low-lying, uniform, peneplained surface with a few minor ridges and knobs controlled primarily by the structure and stratigraphy of the underlying strata. A thin sheet of red, sandy and silty dolomitic shale or siltstone was laid down over this surface with the thickness of the red beds controlled by the topography, and possibly also by minor tectonic activity during Amaranth time.

The coarser clastic, arkosic material was probably derived primarily from a strongly uplifted, highly dissected basement complex of granitoid igneous and metamorphic rocks, located to the southwest in the Cordilleran orogenic belt. Some quartzose sand may have been derived from an eastern granitic or sedimentary source. The red, argillaceous material was probably derived from the western source area as well, or it may be in part a residual soil on erosion surface.

The sediments were deposited in an extremely arid climate with alternating marine evaporitic, and terrestrial oxidizing conditions. Marine inundations were apparently more numerous in the southwestern part of the area, as is indicated by the increase in anhydrite content. The local environment, such as pond and stream channel, probably controlled the size distribution of the sediments.

The amount of coarse clastic material being deposited decreased with time, probably due to decreased tectonism in the source area, and the upper red beds become predominantly shale. Variegated green and red shales reported from the upper part of the red beds probably indicate the first stages of marine transgression, which was culminated by the widespread marine evaporitic deposits of the Middle Amaranth. The interbedded anhydrite and shale of the Middle Amaranth indicate deposition under restricted marine environment, much as in the Lower Amaranth, but with marine rather than terrestrial conditions predominant. A few thin red beds also occur interbedded with the evaporites.

The cherty and oolitic limestones and dolomites of the Upper Amaranth indicate deposition under normal marine conditions, probably shallow water with a very slow rate of sedimentation and little influx of clastic material. The Amaranth probably represents a cycle of marine transpression from non-marine red beds, to marine evaporites, and finally to normal marine limestones. By the end of Amaranth time, almost all of the topographic relief on the pre-Amaranth erosion surface had apparently been buried, and the depositional surface was flat as indicated by the thin, persistent, shallow water marine limestones of the Upper Amaranth. The area around Wawanesa and north of Daly remained above the depositional surface until later Jurassic time.

CHAPTER VIII

AGE AND CORRELATION OF THE LOWER AMARANTH

The Lower Amaranth is easily correlated throughout the southwestern part of the map-area, where it forms an almost continuous blanket of sediments overlying eroded Devonian and Mississippian strata. Wickenden (1945, corrigenda 1953) stated that "no beds of red dolomitic silt similar to the Amaranth occur above the Mississippian." It is true that the Lower Amaranth red beds do thin towards the erosional edge of the Mississippian and are absent in a few areas such as Wawanesa, but on the basis of more recent subsurface information red siltstones of the Lower Amaranth definitely are present above Mississippian strata southwest of the erosional edge of the Mississippian and attain a maximum thickness of about one hundred and fifty feet in the map-area.

No fossils have yet been found in the Lower Amaranth, so it cannot be dated definitely. The Lower, Middle, and Upper Amaranth members are gradational with no indication of unconformity between the units, and the entire Amaranth is believed to be of the same age. Because the Amaranth shows only a slight disconformity with the overlying Jurassic strata, and because the distribution pattern of the Amaranth is very similar to that of the overlying Jurassic strata the writer believes that the entire Amaranth formation is Jurassic in age.

To the south of the map-area, correlation of the Lower Amaranth becomes increasingly difficult. The pre-Amaranth unconformity truncates progressively younger strata towards the center of the Williston Basin area, and some of these strata such as the Kibbey, Amsden, Opeche, and Spearfish formations contain red beds similar in lithology to the Lower Amaranth.
This unconformable superposition of red beds has caused considerable difficulty in local correlations in North Dakota and eastern Montana.

In the central part of the Williston Basin, Towse (1954) indicated that Jurassic red beds equivalent to the Lower Amaranth overlie Triassic red beds of the Spearfish formation, however the Spearfish formation is believed to pinch out to the north, and probably is not present in Manitoba.

The Amaranth appears to be correlative with the Jurassic Gypsum Spring formation of Montana and the basal Piper of North Dakota. The Lower and Middle Amaranth correlate with the Watrous formation of Saskatchewan.

Until accurate regional correlations are worked out the term Amaranth would appear to be the preferable formational name to use in the map-area, especially as the age of the unit in Manitoba is uncertain.

CHAPTER IX

ECONOMIC GEOLOGY

Lyleton Formation -- The Lyleton formation is of no direct economic importance at present, and its primary usefulness is as a marker horizon in subsurface studies, and structure contour work.

Amaranth Formation -- The Upper Amaranth is commercially important as a source of gypsum, and is being worked at the present time in the mine at Amaranth. Further production should be possible along the erosional edge of the Amaranth, where the anhydrite has been subjected to surface alteration to gypsum, and where the glacial drift is sufficiently thin to permit profitable mining.

The gypsum mine at Gypsumville may also be producing from the Amaranth formation. According to the geological map of Manitoba (G. S. C. Map 850A) Gypsumville is located west of the erosional edge of the Amaranth, and occurs in an area of Silurian outcrop. As the Lower Amaranth does not show any pronounced thinning to the east it is possible that the gypsum mined at Gypsumville is actually from the Amaranth formation and the Amaranth is resting directly on Silurian rocks as an outlier. It is also possible that the gypsum is of Silurian age, although Baillie (1951) also believes that it is more likely Amaranth in age.

In the subsurface the Lower Amaranth has no direct economic importance at present. In some wells considerable black, asphaltic looking material occurs at the base of the Lower Amaranth. This material is probably the result of an oil seep on the pre-Amaranth erosion surface. Such occurrences of asphaltic material should be favorable indicators of oil in the underlying formations.

No evidence of oil has been found in the Lower Amaranth in Manitoba, except for this basal bituminous zone. However, a well drilled in Bottineau County, North Dakota, near the Manitoba border (Sec. 21-161N-79W) was completed as a producer in July 1955, with production apparently coming from the lower part of the Spearfish, or Lower Amaranth equivalent. The possibility of oil production from the Lower Amaranth in southwestern Manitoba thus cannot be overlooked, especially in the extreme southwest where the Lower Amaranth becomes more sandy and porous.

The relationship of the thickness of the Lower Amaranth to the erosional edge of the Mississippian is also very useful in determing if Mississippian strata are present in a well, even before such strata are drilled. Near the erosional edge of the Mississippian the Lower Amaranth red beds are thin or absent when Mississippian strata are present, but immediately to the northeast of the erosional edge of the Mississippian, where the Lower Amaranth rests on Devonian rocks, the red beds are from

100 to 200 feet thick. Thus if a thick red bed section is present in any well drilled near the erosional edge of the Mississippian, this well will not show any Mississippian strata. Conversely, if the Lower Amaranth red beds are thin or absent in the same area, Mississippian strata will be present in the section.

This relationship has been found to hold true in all wells examined by the writer to date, although the interpretation can be complicated by structure, as in the area north of Daly, where thinning of the Lower Amaranth over Mississippian structures and thinning due to the topographic effect of the Mississippian escarpment are superimposed.

The relationship of Lower Amaranth thickness to structures in the underlying Mississippian strata may also prove to be useful in locating potential oil reservoirs. Any local area of unusually thin Lower Amaranth, except along the erosional edge of the Mississippian, indicates the possibility of anticlinal or domal structures in the underlying strata that might possibly act as oil reservoirs. All oil fields in Manitoba show some thinning of the Lower Amaranth in the producing area, and in some instances the producing area may be outlined by Lower Amaranth isopachs, as in the case of the Whitewater field.

The Amaranth is indirectly important because of the secondary tight, evaporitic zone at the top of the Mississippian, immediately underlying the Lower Amaranth. In many areas, such as Daly, the evaporitic zone acts as an impermeable cap rock over the oil reservoir. Most oil fields in Manitoba are related to this evaporitic zone rather than to any stratigraphic horizon in the Mississippian.

CHAPTER X

General Conclusions

(1) The Lower Amaranth red beds were deposited on a profound erosion surface, and overlie Paleozoic rocks of Mississippian, Devonian, and possibly Silurian age in Southwestern Manitoba.

(2) The Lower Amaranth forms a thin relatively uniform blanket of sediments deposited under stable to slightly unstable shelf conditions, in an arid, terrestrial to transitional environment. The thickness of the sediments is controlled by the topography of the pre-Amaranth erosion surface, and possibly by minor contemporaneous tectonism.

(3) The age of the Lower Amaranth is indeterminate, but general considerations indicate a Jurassic or at earliest a Triassic age for the red beds.

(4) Lower Amaranth red beds are predominately an anhydritic siltstone, sandy at the base and becoming increasingly argillaceous, and dolomitic towards the top. The average grain size decreases towards the top of the section. The grain size also appears to decrease to the northeast in the map-area.

(5) The Lyleton formation is primarily a sequence of red and green dolomitic shales, containing only very minor coarse material.

(6) The Lyleton is essentially conformable with the overlying Bakken formation and the underlying Nisku formation, and is believed to be Upper Devonian in age, although no definite fossil evidence is available.

(7) The contact between the Lyleton and the Bakken is very difficult to pick in most wells, and it is possible that the two are in part facies equivalents.

(8) The Lyleton and Lower Amaranth are separate, distinctive, stratigraphic and lithologic units of markedly different age. They can easily be correlated throughout the map-area, and can generally be distinguished in core and well cuttings.

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APPENDIX I

WELL DATA

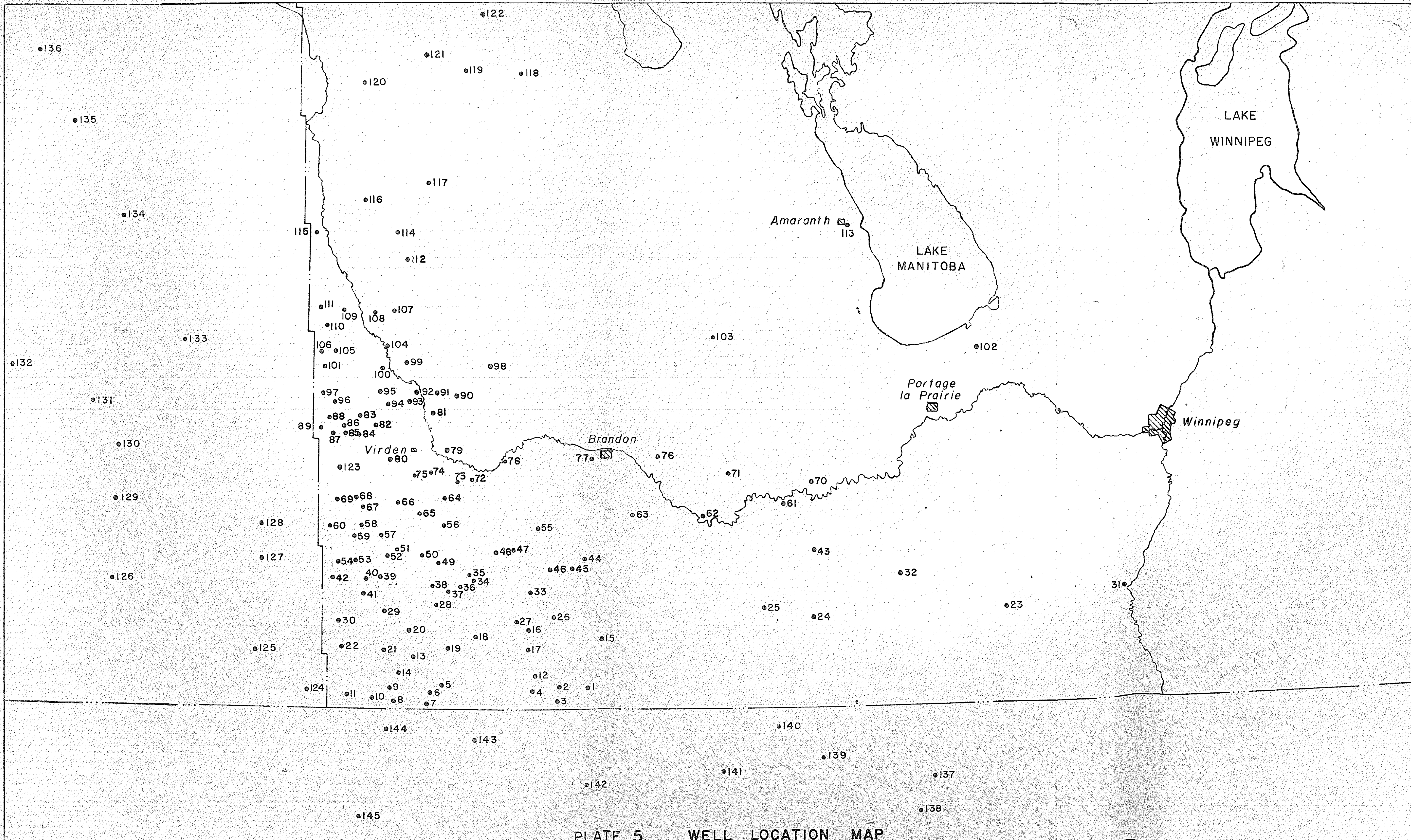


PLATE 5. WELL LOCATION MAP

No.	Company	Well Name	Location Manitoba	Elev.	Amaranth Upper	Amaranth Middle	Amaranth Lower	Mississ.	Bakken	Lyleton	Devonian
1	Petcal Homestead et al	Turtle Mountain #1	10-26-1-20WPM	2247	2863	2914	3082	3190	3330?	3442	3481
2	Royalite Triad et al	Max Lake #1	4-36-1-21WPM	2287	2954	3057	3124	3272	3516 ?	3628	3652
3	Royalite Triad et al	Lulu Lake #1	16-14-1-21WPM	2296	2988 ?	3100	3210	3296	3570	3681 ?	3714
4	Baysel Calstan	Sharp Lake 3-27	3-27-1-22WPM	2183	2982	3100	3210	3300	3790		
5	Angle	Dando 32-3	3-32-1-25WPM	1554	2615	2750	2873	2990	3807	3845	3895
7	Calstan	Waskada 9-13	9-13-1-26WPM	1543	2650	2786 ?	2902	3010	3728	3785	3893
6	Calstan	Waskada 16-13	16-13-1-26WPM	1534	2650	2790 ?	2905	3022			
8	Souris Valley	Downey #1	11-9-1-27WPM	1495	2800	2960	3080	3212			
9	Souris Valley	Robert Moore #1	5-20-1-27WPM	1491	2800 ?	2930	3070	3200	4070	4105 ?	4160
10	Souris Valley	Gordon White #1	5-14-1-28WPM	1494	2890 ?	2945	3180	3305	4210	4250 ?	4325
11	Poplar Gas Ex Admiral	Antler #1	8-15-1-29WPM	1538	3070	3212	3328	3462			
12	J.P.Owen	Owen #1	8-11-2-22WPM	2124	2835	2 946	3070	3180	3581		
13	J.P.Owen	North Coulter 5-32	5-32-2-26WPM	1490	2683	2745	2885	3000	3700	?	
14	Angle	Gould 14-3	3-14-2-27WPM	1494	2698	2830	2968	3080			
15	Baysel Calstan	Boissevain 3-20	3-20-3-19WPM	1689	2145	2230	2347	2382	2538	2590	2625
16	Calstan	Whitewater 15-36	15-36-3-22WPM	1638	2220	2302	2440	2495	2844	2855 ?	2890
17	J.P.Owen	Ellis 3-10	3-10-3-22WPM	1649	2318	2414	2566	2648	3053	3072 ?	3100
18	Dakota	Cassan 5-32	5-32-3-24WPM	1592	2370	2472	2612	2692	3289	3315 ?	3350
19	Anglo Souris Valley	McKee 15-1	1-15-3-25WPM	1554	2435	2550	2695	2798			
20	Cleary	McCallum 4-32	4-32-3-26WPM	1455	2472	2427	2710	2822	3476		
21	Anglo	Skelton 4-14	14-4-3-27WPM	1486	2685	2780	2935	3040			
22	Imperial	Pierson 13-2M	13-2-3-29WPM	1562	2958	3030	3170	3280			
23	Hart Green	Wakely #1	1-28-4-4WPM	860	320	440	470			Silurian (555)	
24	Sweet Grass	Pilot Mound #1	3-9-4-11WPM	1546	1455	1570	1665	-x-	-x-	-x-	1740
25	Dome et al	Greenway 16-33	16-33-4-13WPM	1427	1390 ?	1510	1585	-x-	-x-	-x-	1680
26	British American	Union Croll 4-13	4-13-4-21WPM	1646	2147	2220	2355	2433	2647	2665 ?	2693
27	Dome Harris Cox	Whitewater Lake 4-4	4-4-4-22WPM	1653	2278	2368	2505	2597	2958	2975	3008
28	Souris Valley Y.P.F.	McInnes #1	8-20-4-25WPM	1480	2350	2370	2525	2635	3181	3210 ?	3280
29	Anglo	Coates 20-13	13-20-4-27WPM	1505	2555	2645	2812	2920			
30	J.P.Owen	Brodie 1-11	1-11-4-29WPM	1576	2812	2860 ?	3040	3160	3850	3890 ?	3967
31	Red River Oil	Red River Oil #2	2-1-5-1WPM	795	-x-	-x-	-x-	-x-	-x-	-x-	-x-
32	Sweet Grass	Altamont #1	2-35-5-8WPM	1449	1080	1150	1240 ?	-x-	-x-	-x-	1250
33	Souris Valley	Warnez 13-5	5-13-5-22WPM	1635	2120	2195	2320	2335	2654	2675 ?	2715
34	Royalite Triad et al	East Hartney #1	7-27-5-24WPM	1453	1885 ?	1950	2015	2067	2478	2535 ?	2572
35	Calstan	Hartney 16-33	16-33-5-24WPM	1420	-x-	-x-	-x-	-x-	-x-	-x-	2910
36	Madison	Lauder 1-19	1-19-5-24WPM	1444	-x-	-x-	-x-	2080	2625	2655	2792
37	Calstan	Lauder 9-14	9-14-5-25WPM	1444	2015	2120	2280	2330	2895	2925	2995
38	Sapphire	Bernice #1	10-18-5-25WPM	1439	2200	2270	2432	2530	3012		
39	Dome Harris Cox	North Broomhill 5-31	5-31-5-27WPM	1528	2525 ?	2552	2730	2835	3400		
40	Cleary	Wilson 15-22	15-22-5-28WPM	1531	2595 ?	2630	2795	2875			
41	Widney Can. Sup.	Broomhill #1	3-3-5-28WPM	1544	2632	2688	2840	2940	3612	?	
42	Calstan	North Tilston 4-3	4-3-6-29WPM	1645	2730	2790	2960	3065	3652	3690	3792
43	Baysel	Bruxelles 1-27	1-27-6-11WPM	1681	1470	1512 ?	1660 ?	-x-	-x-	-x-	1730

Note: Formation tops picked from electric and radioactivity logs only.
-x- indicates unit missing from the section.

Where Upper and Middle Amaranth cannot be distinguished on the logs the tof the Amaranth is called the Upper Amaranth and the Lower Amaranth indica by a (?).

Manitoba

No.	Company	Well Name	Location	Elev.	Amaranth Upper	Amaranth Middle	Amaranth Lower	Mississ.	Bakken	Lyleton	Devonian
44	McCarty and Coleman	Sands 2-13	2-13-6-20WPM	1543	1803	1865	1945	1954	2103	2140 ?	2168
45	McCarty and Coleman	Dobson 6-4	6-4-6-20WPM	1570	1895	1965	2075	2110	2252	2282 ?	2310
46	McCarty and Coleman	Moffatt 16-3	16-3-6-21WPM	1529	1890	1974	2103	2144	2302	2325 ?	2362
47	McCarty and Coleman	Forbes 1-31	1-31-6-22WPM	1442	1852	2922	2020	2035	2320	2354 ?	2412
48	McCarty and Coleman	Morrice 12-28	12-28-6-23WPM	1420	1890	1960	2072	2090	2418	2435	2500
49	Reality Dom. Min. Sup.	Pipestone #1	6-16-6-25WPM	1426	2042	2140	2295	2384	2849	2870 ?	2924
50	Sapphire	South Pipestone #1	12-24-6-26WPM	1431	2112 ?	2192	2350	2408	2890	2910 ?	2964
51	Perry Fulk	Fairlie #1	6-36-6-27WPM	1486	2262	2308	2472	2575	3015	3050 ?	3110
52	Calstan	Reston 7-27	7-27-6-27WPM	1483	2260	2370 ?	2540	2640	3082	3120 ?	3182
53	Souris Valley	Stoney Creek 2-17	2-17-6-28WPM	1565	2582	2658	2820	2930			
54	Dome Harris Cox	North Tilston 7-15	7-15-6-29WPM	1628	2652	2730	2900	3015	3532		
55	McCarty and Coleman	Janz 16-20	16-20-7-21WPM	1438	1720	1785	1876	1890	2059	2090 ?	2130
56	Calstan	Findlay 9-26	9-26-7-25WPM	1421	1940	2005	2140	2208	2562	2582 ?	2630
57	Northern	Rustin 2-16	2-16-7-27WPM	1511	2347	2375	2538	2633	3071	3108 ?	3165
58	Calstan	Linklater 10-21	10-21-7-28WPM	1629	2462	2520	2673	2718	3062	3095	3192
59	Calstan	Linklater 2-21	2-21-7-28WPM	1618	2487	2514	2657	2700	3064	3090 ?	3188
60	Northern	West Sinclair 2-28	2-28-7-29WPM	1724	2658	2688	2856	2932	3310	3335 ?	
61	Great Northern	Spruce Wood #1	16-21-8-12WPM	1145	875	925	1045	-x-	-x-	-x-	1145
62	Calstan	Spruce Wood S.T. #3	10-4-8-15WPM	1523	1060	1115	1240	-x-	-x-	-x-	1335
63	Calstan	Wawanesa 3-1	3-1-8-18WPM	1364	-x-	-x-	-x-	1332	1444	1465 ?	1500
64	Canadian Devonian	Oak Lake #1	4-25-8-25WPM	1420	1890	1940	2005	2020	2358	2400 ?	2462
65	Dome Harris Cox	Belleview 16-1	16-1-8-26WPM	1432	2110	2138 ?	2230	2365	2705 ?		
66	Royalite Triad	Scarth #1	14-19-8-26WPM	1481	2088	2150	2300	2392	2750		
67	Calstan	Ewart Prov. 4-14	4-14-8-28WPM	1310	2370 ?	2395	2510	2530	2882	2935 ?	2988
68	Calstan	Cromer Prov. 8-27	8-27-8-28WPM	1547	2300 ?	?	2432	2450	2800	2840 ?	
69	Dome Harris Cox	West Ewart 12-15	12-15-8-29WPM	1723	2570	2595	2748	2782	3135 ?		
70	National Bulk Carriers	N.B.C. Prov. 13-10	13-10-9-11WPM	1187	812	878	978	-x-	-x-	-x-	1070
71	Calstan	Spruce Woods S.T. #2	1-20-9-14WPM	1204	973	1040	1145	-x-	-x-	-x-	1240
72	Dome Harris Cox	Algar 1-13	1-13-9-24WPM	1419	1765 ?	1812	1940	-x-	?	2080 ?	2150
73	Dome Harris Cox	North Oak Lake 4-17	4-17-9-24WPM	1431	1815	1855	1975	2020	2128	?	
74	Calstan	Routledge Prov. 13-29	13-29-9-25WPM	1434	1865	1880 ?	1975	1988	2300	2338	2395
75	Souris Valley W.B.	Jeffrey 1-22	1-22-9-26WPM	1446	1892	1932	2046	2075	2427 ?	2460 ?	2502
76	Calstan	Spruce Woods S.T. #1	13-12-10-17WPM	1260	1118	1168	1274	-x-	-x-	-x-	1385
77	Man. Gas and Oil Synd.	Brandon Coutts #2	14-16-10-19WPM	1319	1305	1362	1472	-x-	-x-	-x-	1590
78	Sapphire	North Griswold #1	8-1-10-23WPM	1427	1670	1705 ?	1820	-x-	-x-	-x-	1940
79	Dome Harris Cox	Routledge 3-13	3-13-10-25WPM	1215	1572	?	1700	1745	1928		
80	Imperial	Virden 5-3	5-3-10-27WPM	1568	2110	?	2266	2320	2743	2770 ?	
81	Dome Harris Cox	West Lenore 2-32	2-32-11-25WPM	1469	1730	1800	1834	1842	2110		
82	Calstan	Hargrave Prov. 15-16	15-16-11-27WPM	1611	2005	2055	2110 ?	2120	2408	2437	2440
83	Sapphire	Reaper #1	12-36-11-28WPM	1648	2075	2100	2220	2235	2563	2597 ?	2664
84	Sapphire	North Daly #1	11-2-11-28WPM	1661	2214	2232	2360	2436	2738		
85	Sapphire	North West Daly #1	9-5-11-28WPM	1704	2230 ?	?	2414	2442	2747	2770 ?	
86	Baysel Calstan	Elkhorn 16-18A	16-18-11-28WPM	1729	2220 ?	2280	2415	2445			
87	Cleary	Wood 16-3	16-3-11-29WPM	1754	2330	2353	2492	2526	2818	2855 ?	

No.	Company	Well Name	Location	Elev.	Amaranth Upper	Amaranth Middle	Amaranth Lower	Mississ.	Bakken	Lyleton	Devonian
			Manitoba								
88	Crawford E. Smith	Jean Lucien Canart #1	6-16-11-29WPM	1750	2328 ?	?	2420	2430			
89	Calstan	Elkhorn 7-8A	7-8-11-29WPM	1783	2380 ?	?	2490	2503	2773	2810 ?	2893
90	Imperial	Blossom 3-17	3-17-12-24WPM	1551	1738	1768 ?	1853	-x-	1941 ?	1990 ?	2023 ?
91	H.L.Hunt	Isaac Ratzlaff 2-26	2-26-12-25WPM	1550	1848	1875 ?	1990	-x-	-x-	-x-	2050 ?
92	Calstan	Harmsworth Prov. 6-24	6-24-12-26WPM	1494	1710	1735 ?	1780	1792	2079	2110 ?	2155
93	Dome Harris Cox	Harmsworth 1-10	1-10-12-26WPM	1497	1757	1820 ?	1832 ?	1848	2172	2200 ?	2250
94	Dome Harris Cox	South Two Creeks 4-12	4-12-12-27WPM	1566	1812 ?	?	1904	1920	2223	2245	2305
95	Calstan	Two Creeks 9-22	9-22-12-27WPM	1572	1655	?	1787 ?	1822	2114	2140 ?	2196
96	Sapphire	Kirkella 14-12	14-12-12-29WPM	1684	2158	2175	2258	2280	2572	2605	2694
97	Calstan	Kirkella 5-21	5-21-12-29WPM	1729	2185	2202	2282	2298	2616	2670 ?	2770
98	Imperial	Norman 4-27	4-27-13-23WPM	1686	1820	?	1940	-x-	-x-	-x-	2060
99	Dome Harris Cox	Miniota 12-28	12-28-13-26WPM	1487	1720 ?	?	1780 ?	1788	1882	1900	1970
100	Sapphire	West Miniota #1	4-20-13-27WPM	1565	1715 ?	?	?	1756	2010	2040	2102
101	Sapphire	Manson Town Sapph. Hend.#1	3-28-13-29WPM	1673	2010	?	2015 ?	2025	2270	2310 ?	2412
102	Baum Fiel	Bonnie Doon 7-11	7-11-14-5WPM	830	-x-	-x-	-x-	-x-	-x-	-x-	-x-
103	Neepawa Salt Comp.	Neepawa #2	9-33-14-15WPM	1242	750	770	850	-x-	-x-	-x-	,990
104	Can. Oil and Gas Res.	Uno #1	15-10-14-27WPM	1293	1404	?	1415 ?	1433	1610	1630	1705
105	Sapphire	West Willen #1	9-11-14-21WPM	1631	1870	?	1895 ?	1900	2118	2160 ?	2238
106	J.P.Owen	Poole Manson 14-5	14-5-14-29WPM	1678	1986	?	2000 ?	2012	2250	2280 ?	2380
107	Pathfinder and Assoc.	Milne 29-4	4-29-15-26WPM	1637	1782 ?	?	1792 ?	1802 ?	1848	1870 ?	1945
108	Petcal	Long Island Birdtail #1	9-21-15-27WPM	1540	-x-	-x-	-x-	1530	1698	1730 ?	1785
109	Calstan	Treat Prov. 15-29	15-29-15-28WPM	1547	1520 ?	?	1550	1572	1794	1830	1925
110	J.P.Owen	McAuley 12-2	12-21-5-29WPM	1604	-x-	-x-	-x-	1793	2023	2055 ?	2138
111	J.P.Owen	Ross V.L.A. 3-33	3-33-15-29WPM	1588	1640 ?	?	?	1653	1895	1920 ?	2024
112	Imperial	Birtle #1	1-27-17-26WPM	1791	1575 ?	1665	1730	-x-	-x-	1750 ?	1785
113	Amaranth Gypsum Co.	Amaranth Test Hole #1	?-25-18-10WPM	875	-x-	-x-	117	-x-	-x-	-x-	177
114	Anglo American	Birdtail 4-30	4-30-18-26WPM	1809	1680	1722	1772 ?	-x-	-x-	-x-	1792
115	Imperial	Madeline #1	16-18-18-29WPM	1597	-x-	-x-	-x-	1370	1605	1672 ?	1745
116	Imperial	Foxwarren #1	16-32-19-27WPM	1821	-x-	-x-	-x-	1535	1624	1640 ?	1745
117	Waywasekapow Oil Co.	Jean Cleland #3	4-22-20-25WPM	1796	1612 ?	?	1675	-x-	-x-	-x-	1761
118	British American	Gilbert Plains #1	16-18-24-21WPM	1339	570 ?	?	605	-x-	-x-	-x-	690
119	British American	Grandview #1	16-30-24-23WPM	1433	755	795 ?	-x-	-x-	-x-	-x-	873
120	Imperial	Blue Wing Lake 13-4	13-4-24-27WPM	1881	-x-	-x-	1440 ?	-x-	-x-	-x-	1456
121	British American	Grandview #3	16-15-25-25WPM	1581	1130 ?	?	?	-x-	-x-	-x-	1193
122	British American	Grandview #4	13-24-10-27WPM	1546	793	?	850 ?	-x-	-x-	-x-	890
150	Calstan	Pierson Prov. 2-29	2-29-2-29WPM	1578	2987	3120	3226	3336	4196	4230 ?	4332
151	Calstan	Daly 15-18	15-18-10-27WPM	1624	2120 ?	?	2155 ?	2165	2502	2540	2600
152	Souris Valley	Pascar Studer 24-1	1-24-10-27WPM	1503	2000	2030	2105	2120	2473	2505	2558
			Saskatchewan								
124	Socony	S. Gainsborough	16-29-1-30WPM	1618	3280 ?	3815 ?	3495	3595	4600	4650 ?	4750
125	Socony	Carievale	16-4-3-32WPM	1617	3430	3520	3670	3765	4850	4930 ?	5030
126	Canadian Gulf	Ludwig #8	8-22-5-4W2	1953	3990 ?	?	4130	4252			
127	Socony	St. Antoine #1	4-24-6-32WPM	1915	not available		3425	3521	4105 ?	4170 ?	4272

No.	Company	Well Name	Location	Elev.	Amaranth Upper	Amaranth Middle	Amaranth Lower	Mississ.	Bakken	Lyleton	Devonian
			Saskatchewan								
128	Socony	Redvers #1	13-36-7-32WPM	1950	3156 ?	?	3300	3418	3880	3932	
129	Tidewater	Arcola #1	1-22-8-4W2	2043	?	3629 ?	?	3893	4620	4666	4838
130	Tidewater	Kenosee Cr. #1	16-23-10-4W2	2471	3740 ?	?	3885	3995	4530 ?	4607	4748
131	Tidewater	Bender Cr. #1	13-11-12-5W2	2498	not available		3770 ?	3910	4342	4386	4552
132	British American	Bemeryside #1	3-11-13-8W2	2214	3310 ?	?	3530	3680	4155 ?	4210 ?	4370
133	Calvan	Wapella #1	16-19-14-1W2	1977	2590 ?	2620 ?	2735	2792	3038	3075 ?	3222
134	Tidewater	Cotham Cr. #1	1-2-19-4W2	1847	1993 ?	2000 ?	2035	2075	2365	2405	2555
135	Sohio	Melville #1	11-12-22-6W2	1795	-x-	-x-	-x-	1740	1955	2025 ?	2120
147	Sohio	East Churchbridge #1	12-32-21-30WPM	1684	-x-	-x-	-x-	-x-	-x-	1430 ?	1530
146	Tidewater	Hillesden Cr. #1	5-30-15-5W2	2151	2900 ?	?	3048	3110	3385	3420 ?	3565
			North Dakota								
137	Union of California	Wohletz #1	C NW SW-32-160N-60W	1612	-x-	-x-	-x-	-x-	-x-	-x-	
138	Union of California	Ellis #1	C NW NE-12-161-60W	1645	-x-	-x-	-x-	-x-	-x-	-x-	
139	Union of California	Restad #1	26-162-64W	1630	-x-	-x-	-x-	-x-	-x-	-x-	
140	Rhodes Langenfeld	Murphy #1	C NW NE-18-163N-65W	1597	-x-	-x-	-x-	-x-	-x-	-x-	
141	Union of California	A.Saari #1	C SW SE-35-161N-68W	1717	2150 ?	?	2360 ?	-x-	-x-	-x-	2490
142	Lion Oil	Sebelius #1	23-161N-73W	?	2435 ?	2480 ?	2630 ?	2652	3258	3270 ?	3300
143	Lion Oil	Magnuson #1	SE SW-2- 163N-77W	1669	2690 ?	2835 ?	2940 ?	3070	3810	3835 ?	3880
144	Zack Brooks	Breneston #1	C SW SE-21-163N-80W	1505	2915 ?	3070 ?	3175 ?	3315 ?			
145	California Co,	Blanche Thompson #1	31-160N-81W	?	3330 ?	?	3610	3850 ?	5330	5365	5460

APPENDIX II

DESCRIPTIONS OF SELECTED LITHOLOGIC SECTIONS

Amaranth Test Hole
(SW$\frac{1}{4}$-25-18-10WPM)

General: This test hole was drilled by the Amaranth Gypsum Co. approximately $\frac{1}{2}$ mile east of the mine shaft. The complete red bed section underlying the gypsum beds was cored, as well as approximately 23' of the underlying Devonian limestone. The upper 3' - 4' consisting of red beds profusely shot with stringers and bands of gypsum was retained by the company. Above the red beds the strata consist essentially of massive relatively pure gypsum, with a few thin shaly bands, overlain by glacial drift. The upper part of the core was retained by the company and is not described in this log.

The whole red bed section can be considered as essentially one lighologic unit showing a gradational change in texture and composition towards the base. The whole unit is moderate reddish orange to reddish brown with a few gray to greenish gray patches which are likely due to local reduction of the pigment. No bands of greenshale were noted in the core.

The upper few feet of core are dolomitic red shale, massive, dense, and tight, showing abundant slickenside surfaces and are profusely shot with stringers of fibrous gypsum and bands of massive pure, orange, coarsely crystalline gypsum. The gypsum is probably an alteration product from original anhydrite, and most of the bands and stringers appear to have been introduced into the red beds along secondary fractures. The gypsum occurs scattered throughout the whole red bed section but becomes much less abundant towards the base.

The dolomitic shale grades downward into a dolomitic silty shale which in turn grades into a sandy argillaceous dolomitic siltstone containing scattered rounded frosted quartz (?) graines. Fine flakes of mica, probably muscovite, are quite abundant towards the base of the red bed section.

The red beds show no structures whatsoever, and appear completely massive throughout. No bedding or cross bedding could be seen, unless the whole red bed section can be classed as a graded bed.

The red beds are underlain by limestone, presumably of Devonian age. Moderate sized breccia fragments of the limestone are found in the bottom few inches of the red beds. The limestone itself is yellowish to slightly orangy gray at the top, showing quite numerous solution cavities, some of which are filled with red bed material. A few thin bands of veinlets of gypsum are also present, and there are a few poorly preserved fossils. Several feet below the base of the Amaranth the limestone grades into a reddish gray, very argillaceous limestone which may correspond to one of the Devonian red beds, however there was not sufficient core taken to permit determination of the age or stratigraphic position of the limestone.

Amaranth Test Hole (Cont'd)

Core #1 121 - 131. Recovered 10'.
1' 0" Dolomitic shale, reddish brown, abundantly shot with stringers of fibrous gypsum.
2' 0" Gypsum, massive, pale orange, coarsely crystalline, contains a few breccia fragments of shale.
7' 0" Predominantly red dolomitic shale, several bands of massive gypsum up to 3" in diameter, also several patches of greenish shale, due to local reduction.

Core #2 131 - 141. Recovered 6'4".
3" Red shale, grading to greenish shale.
5" Massive gypsum.
1' 4" Red shale slightly mottled, feels slightly silty. (entire section is silty from here to base.)
10" Gypsum, massive, few breccia fragments.
3' 3" Shale, fine silty, slightly dolomitic, slightly mottled: a few patches and stringers of gypsum; contains a few rounded frosted quartz (?) grains, medium to coarse grained, The sand occures as patches and lenses.
3" Gypsum.

Core #3 141 - 151. Recovered 10'.
10' 0" Red shaly dolomitic siltstone. From 1' to 2' quite sandy. A few grayish reduction patches, and patches and stringers of gypsum. Gypsum is a very minor constituent from here to the base of the red beds, forming only about 5% of the core.

Core #4 151 - 161. Recovered 10'.
10' 0" Siltstone as above.

Core #5 161 - 171. Recovered 10'.
10' 0" Siltstone, as above but slightly more sandy. Present at 3' and becoming prominent at 6' are small rounded sand size fragments of dolomitic limestone or dolomite associated with the sandy patches. These calcarenite grains occur from here to the base. of the red bed section, and become progressively coarser in size.

Core #6 171 - 181. Recovered 10'.
7' 3" Siltstone as above, but slightly more sandy. At 6' there is the start of a breccia zone, with large, up to 1", angular fragments of dolomitic limestone, probably derived from the underlying eroded Devonian(?) limestone.
2" Breccia contact between limestone and red beds. A mozaic of limestone fragments in a matrix of red siltstone.

Amaranth Test Hole (Cont'd)

Core #6
2' 7" Dolomitic limestone, upper 8" show irregular solution cavities. Light yellowish gray, massive, and dense.

Core #7 181 - 191. Recovered 10'.
3' 10" Dolomitic limestone, quite argillaceous, dense, and tight, shows irregular mottling, mostly shades of yellowish to slightly orangy gray with some purplish red patches. Somewhat fractured and the fractures filled with gypsum. Also a few irregular patches of pale orange crystalline secondary gypsum.
3' Gypsum, massive, crystalline, pale orange.
1' 2" Dolomitic limestone, shades of yellowish gray to slightly purplish, massive, finely crystalline to slightly dense. Shows a fair vuggy porosity, part at least of which is due to fossil solution cavities of cup corals, bryozoc and crinoids. Some of the cavities are filled with gypsum.
2" Gypsum.
3' 0" Dolomitic limestone, gray to yellowish gray, slightly brecciated by gypsum, massive, dense, tight, grades into -
1' 6" Red beds. Very argillaceous dolomitic limestone, mottled shades of pale reds and yellows, massive, dense, tight.

Core #8 191 - 201. Recovered 10'.
5' 8" Red beds as above. Mottling slightly less prominent and color more uniform grayish red.
4' 4" Dolomitic limestone, argillaceous, uniform moderate gray to slightly reddish and greenish.

California Standard Waskada 9-13
(9-13-1-26-WPM)

Lower Amaranth

2905-2993 Not cored.
-3024 Cannot be subdivided into any definate lithologic units. Section is uniform in general but quite variable in detail. Predominantly coarse silstone to very fine grained sandstone, moderate reddish brown to slightly greenish gray in patches. Contains abundant irregular, rounded inclusions or fragments of anhydrite. Biotite and muscovite flakes are very abundant along rough bedding planes. Shows very irregular contorted or pseudo-breccia structure with a few bands showing

some fine bedding and cross-bedding.
Grades to moderately dolomitic in some bands; and patches of medium to coarse well rounded, frosted, and pitted sand grains are abundant. Many sandstone bands show a marked inclination to the core. The sand content increases towards the base of the unit.
The core samples are somewhat mixed up near the Mississippian contact, but the contact appears to be very abrupt with no evidence of a breccia zone.

<u>Mississippian Charles</u> ?

3024 - Dolomite, dense to fine crystalline, light gray to brownish, tight.

<u>General Petrography</u>:

The Mississippian sediments immediately underlying the Amaranth show consederable replacement by anhydrite. Most specimens show intimate intermixtures of anhydrite and dolomite, and one specimen (Fig. 23) shows perfectly rounded single crystals of anhydrite rimmed by finely crystalline dolomite, in a crystalline anhydrite matrix. This is probably the result of replacement by anhydrite of an original calcarenite or oolitic limestone.

The mineralogy of the red beds in Waskada is typical of the Lower Amaranth and is discussed in considerable detail. The following is a detailed petrographic description of a typical sandy bed in the Lower Amaranth. A grain count was made of the coarse sand size fraction of this specimen.

Coarse sand size fraction (50%)	
Quartz	29%
Feldspar (18%)	
Orthoclase	11%
Plagioclase (Albite-Oligoclase)	6%
Microcline	trace
Quartzite	½%
Limestone	½%
Rock fragments (igneous, metamorphic)	2%
Magnetite and Ilmenite	2%
Garnet	trace
Hematite	trace
Tourmaline	trace
Matrix or cement (50%)	
Anhydrite	20-30%
Dolomite	20%
Clay Minerals	(present but cannot estimate)

Some feldspar grains are completely altered or weathered to Kaolinite (?) and some are perfectly fresh and unaltered. All gradations between fresh and completely altered are present. The degree of weathering shows no relation to the degree of roundness or sphericity, as some of the largest and roundest grains of feldspar are perfectly fresh.

Some quartz grains show sharp extinction and few inclusions, some of which are oriented needle-like inclustions of Rutile (?). Other quartz grains show pronounced undulatory extinction, and many of these are aggregates of smaller quartz grains forming a (meta-) quartzite.

Magnetite and garnet grains are associated in thin bands.

Anhydrite occurs as a matrix, especially in the sandy bands, or as irregular to rounded inclusions or fragments of clean crystalline anhydrite.

The carbonate-anhydrite matrix shows in places what appears to be quite strong replacement of the quartz and feldspar grains, though most grains are not replaced. This replacement may result in the frosting and pitting shown by sand grains. The fine clastic fraction of the Waskada section consists of coarse silt to fine sand with the grains angular to slightly subrounded. Sodic plagioclase is a quite common constituent of the silt size fraction. Magnetite and Ilmenite grains are also common, as are Muscovite and Biotite laths in the finer grained bands.

The matrix for the siltstone is predominantly dolomite and/or anhydrite, and is only slightly argillaceous. The matrix is predominantly anhydrite in the coarser grained bands.

The sorting in most specimens was very poor with coarse sand, silt, and clay all present in most specimens.

Anglo-Souris Valley Smart 1-4
(4-1-1-26 WPM)

Lower Amaranth

2950 - 3047 Not Cored

3078 Siltstone, micaceous, argillaceous and dolomitic, with sandy patches. Fragments or irregular inclusions of anhydrite occur in scattered patches throughout. The color ranges from grayish brown to moderately dark reddish brown. The unit is generally massive but shows irregular banding and pseudo-breccia or swirled structure characteristic of the red beds.

Cont'd

-3078 The lower 7' become quite sandy, and immediately above the base, the unit approaches a sandstone, though the sand occurs as patches rather than uniformly distributed throughout the rock. The grains themselves are medium to coarse sand size, showing good to excellent rounding and sphericity. They also show varying degrees of surface frosting. The sand is probably quite feldspathic.

The basal contact is marked by a band of slightly shaly anhydrite, and passes sharply into the underlying Mississippian. No brecciated inclusions of Mississippian were found in the base of the red bed unit.

Mississippian (Charles)

3078- 3081 Sandstone, shades of pale grey, massive tight and fine grained. Matrix is dolomitic. Unit shows some fine irregular color banding and some irregular mottling near the top.

-3082 Dolomite, argillaceous, shows irregular banding in shades of red, brown, and gray; very fine crystalline.

Depth in Feet Lithology

Pascar Hunt No. 1.
(10-9-1-27WPM)

Lower Amaranth

3100 - 3200 Not cored

3200 - 3213 Siltstone, dolomitic, argillaceous, moderate reddish-brown. Contains varying amounts of anhydrite as rounded inclusions irregularly scattered throughout the siltstone matrix. No visible banding or bedding. Some patches show irregular pseudo-breccia structure. Large rounded frosted sand grains become common towards the base. At 3211 grades sharply to light, slightly greenish gray very dolomitic siltstone, with abundant large inclusions of anhydrite, and some angular fragments of dense gray dolomite up to ½" in diameter. Grades to dolomitic argillaceous sandstone in part.

The contact with the underlying Mississippian is sharp and irregular. The breccia fragments are probably from the underlying unit, but the

Cont'd

breccia zone is quite minor.

Mississippian Charles

3213 - Anhydrite, massive, associated with some gray limestone.

General Petrography:

Samples consist of sandy siltstone similar to samples from the Waskada well. The sand is feldspathic, but slightly less so than in Waskada, and the feldspar is somewhat less weathered. The sand is predominantly strained quartz with some unstrained rutilated quartz, chert, garnet, and magnetite. In some specimens the sand grains were 'floating' in a microcrystalline dolomite matrix. The matrix for the siltstone is predominantly dolomitic to anhydritic, but appears somewhat more argillaceous than in Waskada.

J.P. Owen Brodie 1-11
(1-11-4-29WPM)

Lower Amaranth

- 3116 Not cored.

3116 - 3160 Argillaceous siltstone to silty shale, dolomitic, sandy, anhydritic, moderate brownish red. Shows extremely irregular bedding or banding, to quite thin irregular bedded in places. Anhydrite occurs as small scattered irregular to rounded inclusions. Anhydrite inclusions increase in size towards the base where they are 4-5" in diameter.
Sand grains are medium to coarse grained, well rounded and frosted. The sand occurs in patches and lenses, especially in bands containing abundant anhydrite. The sand content increases toward the base of the unit.
The contact with the underlying Mississippian is quite sharp. A few breccia fragments of light gray dense dolomite are present near the base, but are very minor.
The contact with the underlying Mississippian is very sharp.

Depth in feet	Lithology
	<u>Mississippian</u>
3160 -	Dolomite, medium gray to brownish, massive, fine crystalline. Considerable anhydrite as fracture fillings. 3162.5-3163.5--Several breccia zones, with fragments of dolomite and anhydrite, and some red shale and siltstone.
	<u>Calstan Tilston Province 5-32</u> 5-32-5-29WPM
	<u>Lower Amaranth</u>
3020 - 3073	Not cored
3073 - 3097	Siltstone, moderate red argillaceous, dolomitic and anhydritic. Rounded frosted sand grains present below 3078. Anhydrite occurs as irregular rounded inclusions up to several inches in diameter scattered throughout the section, and sometimes concentrated in bands or lenses. Also some thin beds of anhydrite showing gradational lower contact and sharp upper contact with desiccation structures. The darker colored bands are more argillaceous, and the lighter bands are more dolomitic, sandy, and anhydritic. The siltstone shows massive to irregular or pseudo-breccia structures, with some slight bedding and traces of cross bedding in places. Anhydrite becomes more abundant in the bottom 6'. The sand content also seems to increase in the lower part of the section, and the sand and anhydrite seem to be associated. The contact with the underlying Mississippian is quite sharp with no noticeable breccia.
	<u>Mississippian</u>
3097 -	Anhydrite and dolomite.

<u>General Petrography:</u>

Samples consist of sandstone to siltstone.
Mineralogy of the sand is the same as for the Waskada well, consisting quartz, feldspar, garnet, magnetite, chert and dolomite in a matrix of anhydrite or dolomite with only minor argillaceous material.
Muscovite laths are abundant in the finer grained bands.

Depth in Feet	Lithology
	Calstan Ewart Province 4-14 (4-14-8-28-WPM)
	Lower Amaranth
2527 - 2530	Shale, dark reddish brown, massive, slickensides common, crumbles on wetting, grades predominantly anhydrite with abundant anhydrite inclusions or fragments. Sharp contact with -
- 2531	Red shale as above.
- 2532.5	Anhydrite, massive, with few shaly and silty bands and stringers.
- 2533	Dolomite argillaceous, mottled reddish, slightly sandy.
	Mississippian
2533 -	Anhydrite and dolomite, some slickensides, and some oil stain. Also some siltstone. This unit is a breccia zone consisting predominantly of fragments of Mississippian dolomite with minor patches of Amaranth siltstone.

General Petrography:

Composition of sand appears to be the same as in the Waskada well, with the matrix predominantly microcrystalline argillaceous dolomite. Some specimens show fine to medium sandstone in an anhydritic matrix with most grains angular, unlike most Amaranth sand grains of this size which are very well rounded. Siltstone was a minor constituent in most samples examined.

Depth in Feet	Lithology
	Canadian Devonian Creekside Mitchell #1 (10-32-9-27-WPM)
	Lower Amaranth
2311-2322	(Core may be mixed up) Red argillaceous siltstone
-2325	Anhydrite and dolomite.
-2367	Silstone, moderate reddish-brown argillaceous, dolomitic, and micaceous, with large irregular rounded inclusions or fragments of anhydrite scattered throughout. Shows strong mottling in places. Few patches of light greenish gray color due to local reduction of red pigment. Shows contorted or pseudo-breccia structure. Anhydrite

Depth in feet Lithology

content decreases toward the base of the unit. 2342 some rounded, frosted sand grains associated with the lighter colored anhydritic bands. 2356-2358 becomes very sandy grading to silty dolomitic sandstone. Section becomes lighter colored with increase in sand content.

- 2369 Predominantly anhydrite, including marked breccia fragments of dense dolomite and chert.

- 2370 Red siltstone as above.

-2370.8 Breccia, chert and dolomite fragments up to 2" in diameter gray to reddish mottled, in siltstone matrixas above.

-2371 Red siltstone as above.

-2371.5 Breccia as above, very sandy.

- 2372 Dolomite, light gray, fine crystalline to dense, grades to quite sandy. Shows faint bedding or banding.

- 2375 Breccia, fragments of dense light gray dolomite, anhydrite, and chert, up to 3" or more in diameter. Fragments are very angular and slabby, and are in a red siltstone matrix.

Mississippian

2375 - Dolomite, dense, light gray to reddish, cut by anhydrite stringers. Some red to maroon shale.

General Petrography:

Mineralogy of the sand appears to be the same as in the Waskada well. The feldspar content appears to be at least as high as in the Waskada samples, with fresh microcline very abundant. The matrix is primarily dolomitic. Some samples show a mixture of quartz, feldspar, and sand size dolomite grains in an argillaceous dolomite matrix. The matrix for the siltstone is considerably more argillaceous than in the Waskada well.

Dome Harris Cox Miniota 12-28

(12-28-13-26-WPM)

Upper Amaranth

Core #7 1760-1785: Recovered 22'.

3' Dolomite, argillaceous, slightly calcareous, medium light gray-buff. Contains considerable coarse crystalline gypsum and shows some good coarse vuggy porosity. Grades to -

1' Dolomite, light brown, earthy to fine saccharoidal, very good fine pin point porosity.

0' 6" Shale, medium gray, dolomitic to slightly calcareous.

0' 6" Anhydrite and dolomite.

9' 6" Shale, light to medium gray-buff, dolomitic, massive, very crumbly and fractured, trace of anhydrite in some bands. In part shows good fissility. Contains one thin 4" band of fine crystalline, light gray dolomite showing fine pin point porosity.

3' Massive anhydrite with some associated light buff dolomite.

3' Dolomite, light gray, fine crystalline to micro-granular, fair pin point porosity, argillaceous in part.

Lower Amaranth?

1' 6" Shale, bright red, abundant slickensides. Rounded frosted sand grains are common. Some dark brownish angular quartz (?) grains up to $\frac{1}{8}$" in diameter.

Detrital Zone - Mississippian

Core #8 1785-1810 Recovered 8'

8' Breccia zone. Mixture of dolomite and dolomitic limestone and chert fragments with red shale and anhydrite. Pronounced breccia in places, otherwise red shale and anhydrite occur as fracture fillings. Dolomite and dolomitic limestone show typical mottling of Lodgepole limestone. Amount of red shale and anhydrite, and degree of brecciation decrease somewhat towards the base. This unit is a basal Amaranth detrital zone, grading down into weathered, dolomitized Mississippian.

Sohio Standard Viceroy #1
(16-11-6-25W2)

Note: This well is located a considerable distance to the west of the map area, but is included to show the similarity of the section.

Lower Amaranth

4640 - 4698 Not cored

-4816 Shale, pale to moderate red, silty, micaceous, dolomitic. Contains abundant rounded inclusions of anhydrite, and also a few similar inclusions of medium crystalline dolomite. The top 5' are lighter red, and quite silty and sandy. Slickensides are common in the more argillaceous sections. Greenish gray reduction patches are also common.

Depth in feet	Lithology
	Floating sand grains become very abundant toward the base. Shows irregular pseudo-breccia structure. The section is almost identical to that of Waskada, Smart, and other wells in southwestern Manitoba, though the section is slightly more dolomitic and sandy, and considerably thicker. The contact with the Mississippian is missing in the core, but must be extremely sharp. There was no breccia zone at the Mississippian contact.
	<u>Mississippian</u>
4816 -	Dolomite, medium crystalline to dense, partly argillaceous, some anhydrite.

<u>California Standard Scallion Prov. 5-11</u>

(5-11-11-26 WPM)

Depth in feet	Lithology
	<u>Upper Bakken</u>
2228-2239	Shale, black, slightly calcareous, Grades to very dark gray, fossiliferous at the top (conodonts, and brachiopods). Massive, conchoidal fracture.
	<u>Middle Bakken</u>
2239 -2249	Siltstone, dolomitic, argillaceous, massive. Upper part pale to moderate gray to reddish gray, grading downwards to moderate red. Black hair-like markings abundant in the upper part.
-2253	Silstone to fine sandstone, slightly coarser grained than above, calcareous to dolomitic, light greenish-gray. Several bands of dense light green argillaceous dolomite are present.
-2262	Silstone to very fine grained sandstone, argillaceous, dolomitic to slightly calcareous, dark gray to reddish, finely laminated.
	<u>Lower Bakken?</u>
2262-2267	Shale, dark gray to slightly purplish, massive, non-calcareous.
	<u>Lyleton?</u>
2267-2271	Dolomite, very argillaceous, moderate gray to reddish, with some green shaly bands. Massive to slightly brecciated.

Depth in feet	Lithology
- 2275	Breccia, fragments of light gray dolomite in dark gray shale matrix. Some bright green shale, and some very pronounced slickensides. Pyritic.
- 2276	Dolomite, light to moderate gray, containing many small fragments of dark gray shale. Grades through breccia zone into-
- 2280	Shale, dark gray to reddish gray, massive, non-calcareous. Shows greenish reduction patches especially near the top. Thin breccia zone in the middle of the unit consists of dolomite and dark gray and green shale as above. Grades to-
- 2294	Shale, dolomitic to argillaceous dolomite, bright red. Structure varies from massive to very fine contorted or brecciated appearance. Several thin bands of grayish dolomite and several green shale partings. A few bands show fine lamination. Passes sharply into underlying unit with no breccia zone. Few patches of anhydrite at the contact.

Nisku

2294 - Limestone, white to cream colored, massive, dense, some bands of anhydrite.

Royalite Triad Max Lake No. 1
(4-36-1-21 WPM)

Upper Bakken

3590-3609 Shale, black to dark gray, moderately fissile, becomes slightly lighter colored towards the base. Some conodonts. Grades sharply to -

Middle Bakken

3609-3630 Siltstone, coarse grained, to fine sandstone, medium light gray, argillaceous, dolomitic, and slightly pyritic. Grain size increases towards the base and some bands of medium grained sandstone are present. Slightly mottled, with a few dark hairline markings. Some bands are very finely laminated. Grades sharply to -

Lyleton

3630-3643 Shale, slightly dolomitic, light gray to slightly greenish massive, slightly mottled and streaked. Abundant pyrite along fractures. Grades to -

Depth in feet	Lithology
-3645	Red shale, slightly dolomitic. Some breccia fragments.
-3545.5	Shale, light gray.
-3649.5	Red shale, slightly dolomitic, massive. Bottom 1½' contain some fine breccia fragments of dolomite. Passes sharply but with no noticeable unconformity to -
	Nisku
3649.5-3651	Dolomite, light gray, dense, argillaceous, Scattered patches of anhydrite. Grades to -
-3655	Dolomite, buff, fragmental fossiliferous.

California Standard Cromer 8-27
(8-27-8-28 WPM)

Depth in feet	Lithology
	Upper Bakken
2802-2803.3	Black shale, non-calcareous, fissile. Passes sharply to -
	Middle Bakken
2803.3-3812.5	Silstone, very dolomitic at the top, grading to silty dolomite, gray massive, slightly argillaceous. Becomes increasingly coarser grained towards the base, where it grades to a fine sandstone. Dark hair-like markings are quite common. At 2808, becomes finely laminated and fissile. Fine banding continues to the base but fissility decreases, and becomes darker gray to slightly purplish, with some fine reddish bands. Grades to -
	Lyleton
2812.5-2814.2	Dolomitic shale to argillaceous dolomite, very finely laminated to slightly cross bedded. Some bright green dolomitic shale.
-2417.7	Dolomitic shale to argillaceous dolomite, light gray, massive, dense.
-2422.2	Shale, dolomitic, fine irregular banded, medium dark grayish-red to bright green, slightly pyritic. Some bands finely brecciated.
-2427	Dolomitic shale to argillaceous dolomite, light gray, massive, pyritic (as above).

Depth in feet	Lithology
	Canadian Superior Cruickshank 14-4 (14-4-10-28 WPM)
	Upper Bakken
2701- -2702	Shale, medium dark gray, to slightly brownish, Slightly fissile to subconchoidal fracture. Contains abundant conodonts. Becomes more brownish towards the base and grades to -
	Middle Bakken
2702 -2704.5	Dolomite, argillaceous, slightly calcareous, massive, dense to microgranular, pale to moderate grayish-red with irregular light greenish gray reduction patches. Abundant fine black thread-like markings. Slightly silty. Grades to -
-2706	Dolomite, calcareous, argillaceous, massive, tight, pale greenish gray, fine saccharoidal to micro-granular.
-2712	Silty argillaceous dolomite to dolomitic siltstone, finely laminated. Predominantly pale yellowish-gray to brown at top, grading to reddish to purplish gray in the middle, and light gray at base. Becomes slightly micaceous, and slightly less silty at the base. Grades to -
	Lower Bakken?
2712 -2714	Shale, dark purplish to reddish gray, dolomitic, very finely but irregularly banded, fissile, more massive towards the base.
-2715	Finely interbanded pale yellowish brown fine saccharoidal dolomitic limestone, and smooth green shale. Slightly silty.
-2716.6	Shale, slightly dolomitic, grayish red-purple, massive, few round pale greenish gray reduction patches.
	Lyleton?
2716.6-2720.6	Banded and mottled, mixture of green shale to dolomitic shale, and brownish to slightly reddish dolomitic limestone with nodular bands of purplish to reddish gray dolomitic shale as above. Becomes more massive towards the base and grades to -
-2727	Shale, slightly dolomitic, massive, moderate grayish red to slightly purplish, with numerous greenish gray

Depth in feet | Lithology

round reduction patches.

Note: Some core was missing, and the core may have been slightly mixed up in the core boxes, so the above depths and tops may not be quite accurate.

Calstan West Daly Province 8-29
(8-29-10-28 WPM)

Lyleton? or Lower Bakken?

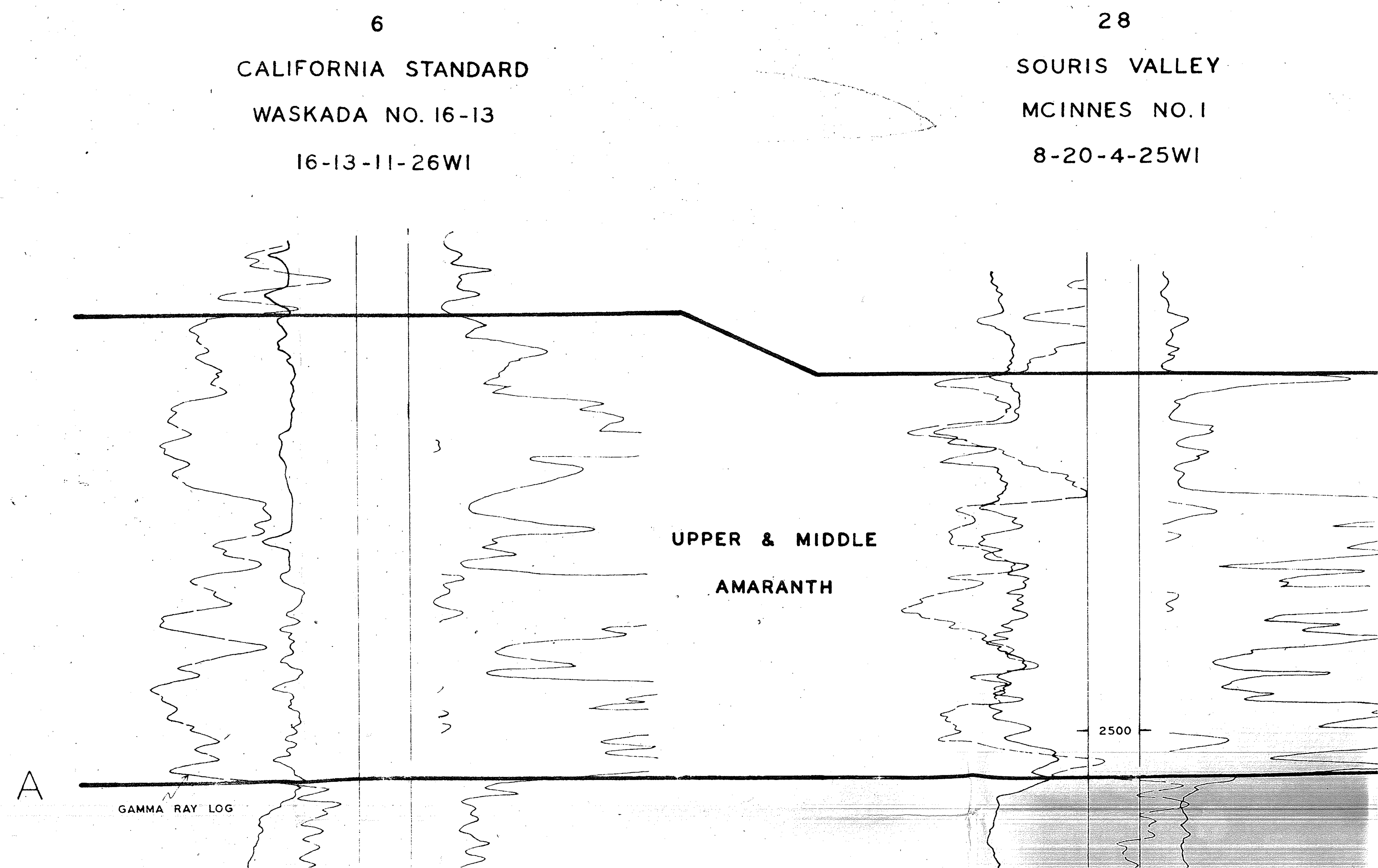
2658-2668 Interbanded reddish-purple argillaceous dolomite or dolomitic shale, and reddish buff slightly argillaceous dolomite, massive, fine crystalline. Banding is fairly irregular and undulating, with some lensing out. Some very fine anhydrite stringers. Buff dolomite predominant at 2660. Some bands show brecciated or pseudo-breccia structure.

2663-2665 mostly massive light greenish gray argillaceous dolomite.

2665-2668 Mostly red to purplish red argillaceous dolomite; fairly uniform, with some pronounced mottling due to reduction around small black inclusions.

General Petrography:

Samples consist of fine crystalline to microcrystalline dolomite, argillaceous in some bands, with only a trace of fine well rounded silt.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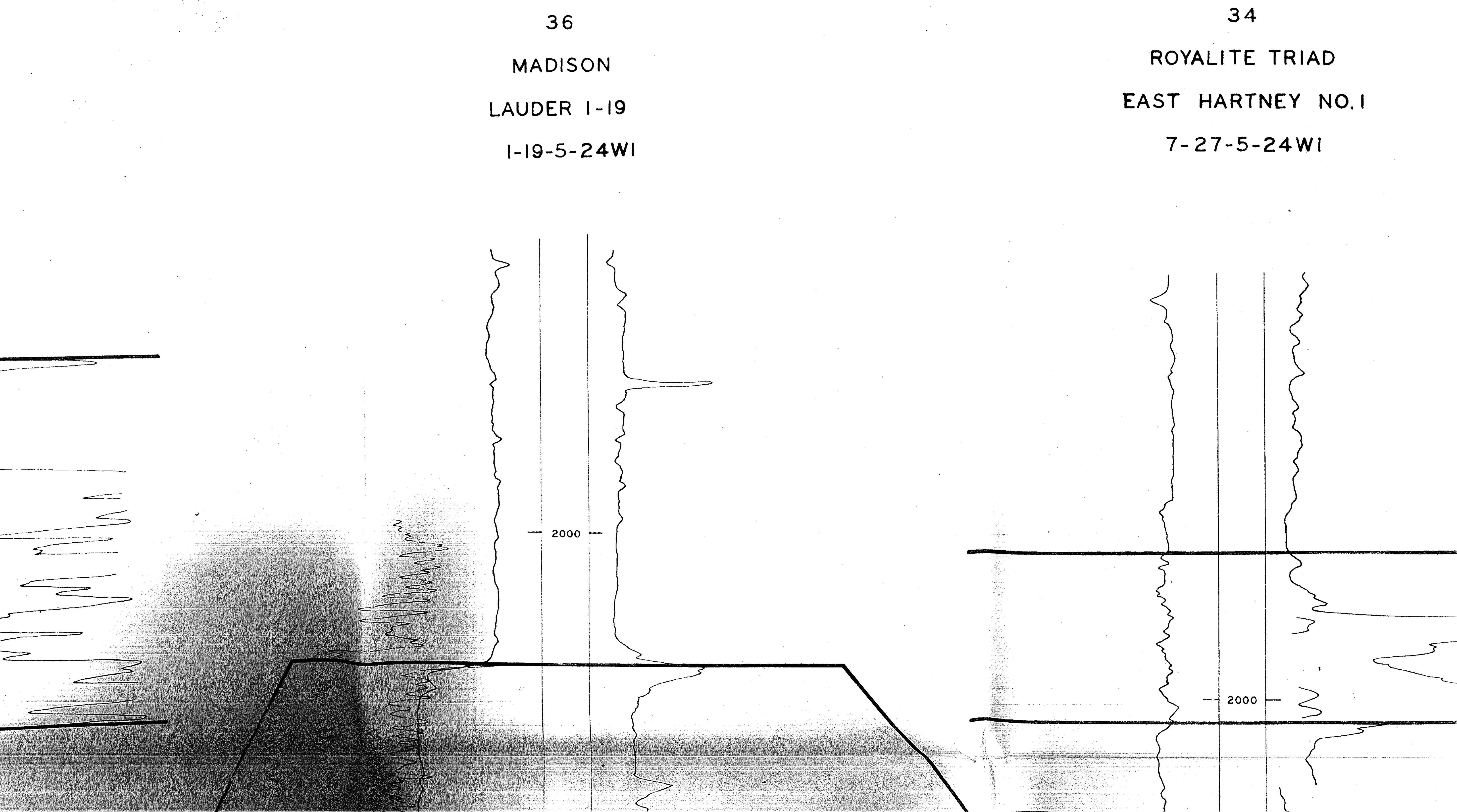
CALIFORNIA STANDARD
WASKADA NO. 16-13
16-13-11-26WI
28
SOURIS VALLEY
MCINNES NO. 1
8-20-4-25WI
UPPER & MIDDLE
AMARANTH
2500
A
GAMMA RAY LOG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MADISON
LAUDER 1-19
1-19-5-24W1
2000
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ROYALITE TRIAD
EAST HARTNEY NO. 1
7-27-5-24W1
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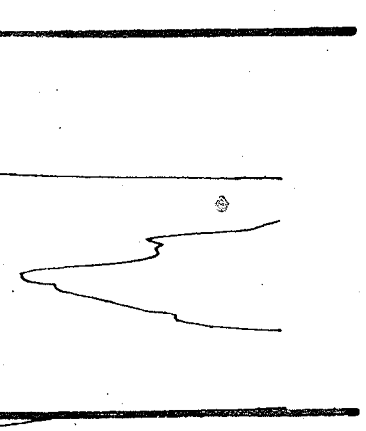

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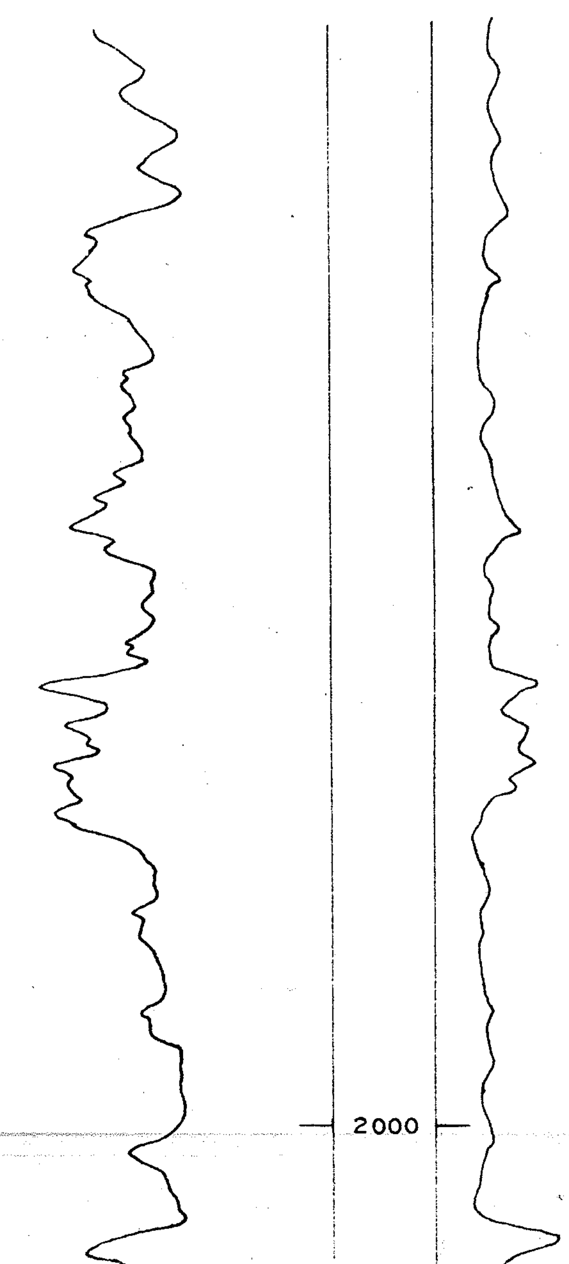
CALIFORNIA STANDARD

HARTNEY NO. 16-33

16-33-5-24WI



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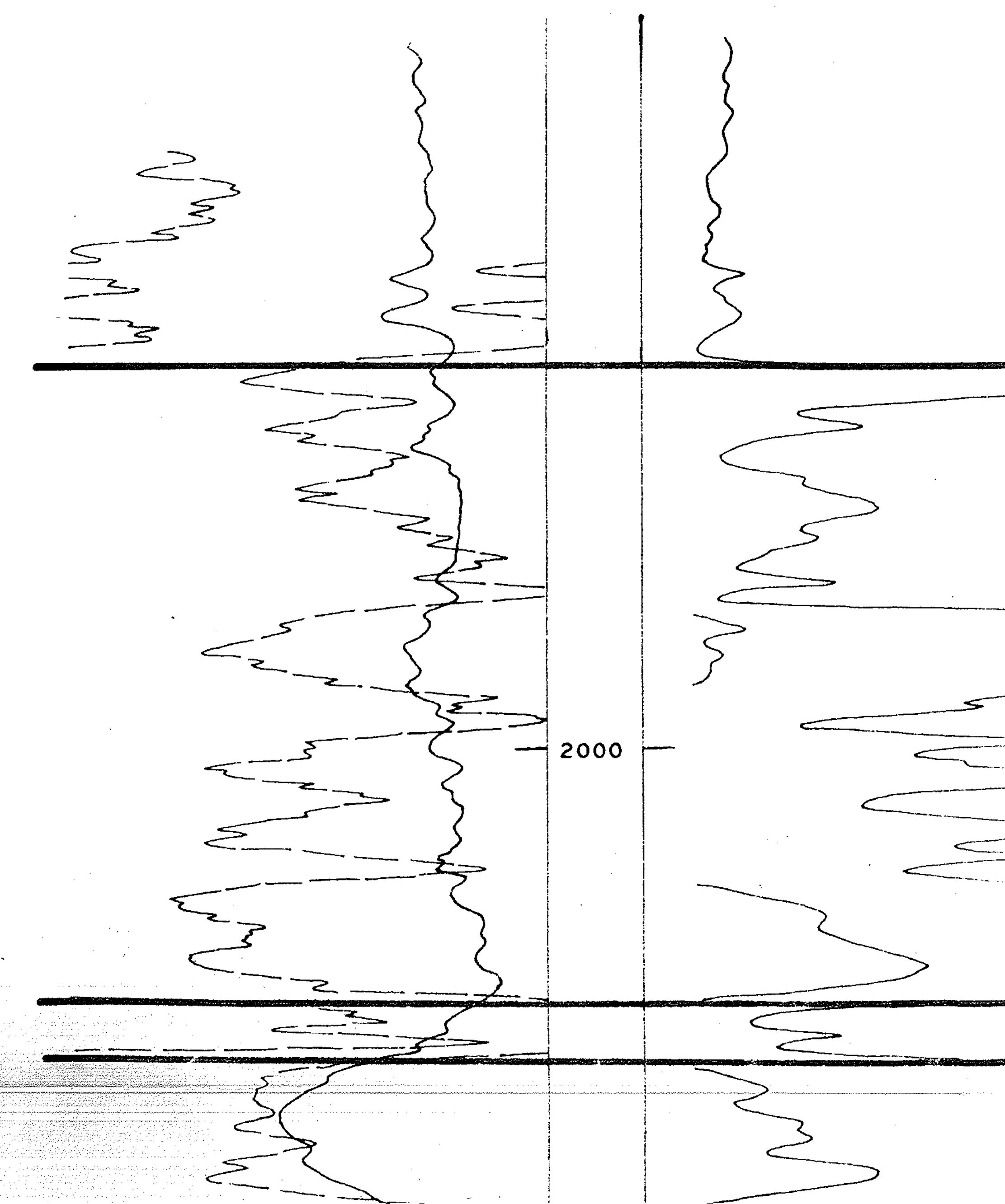
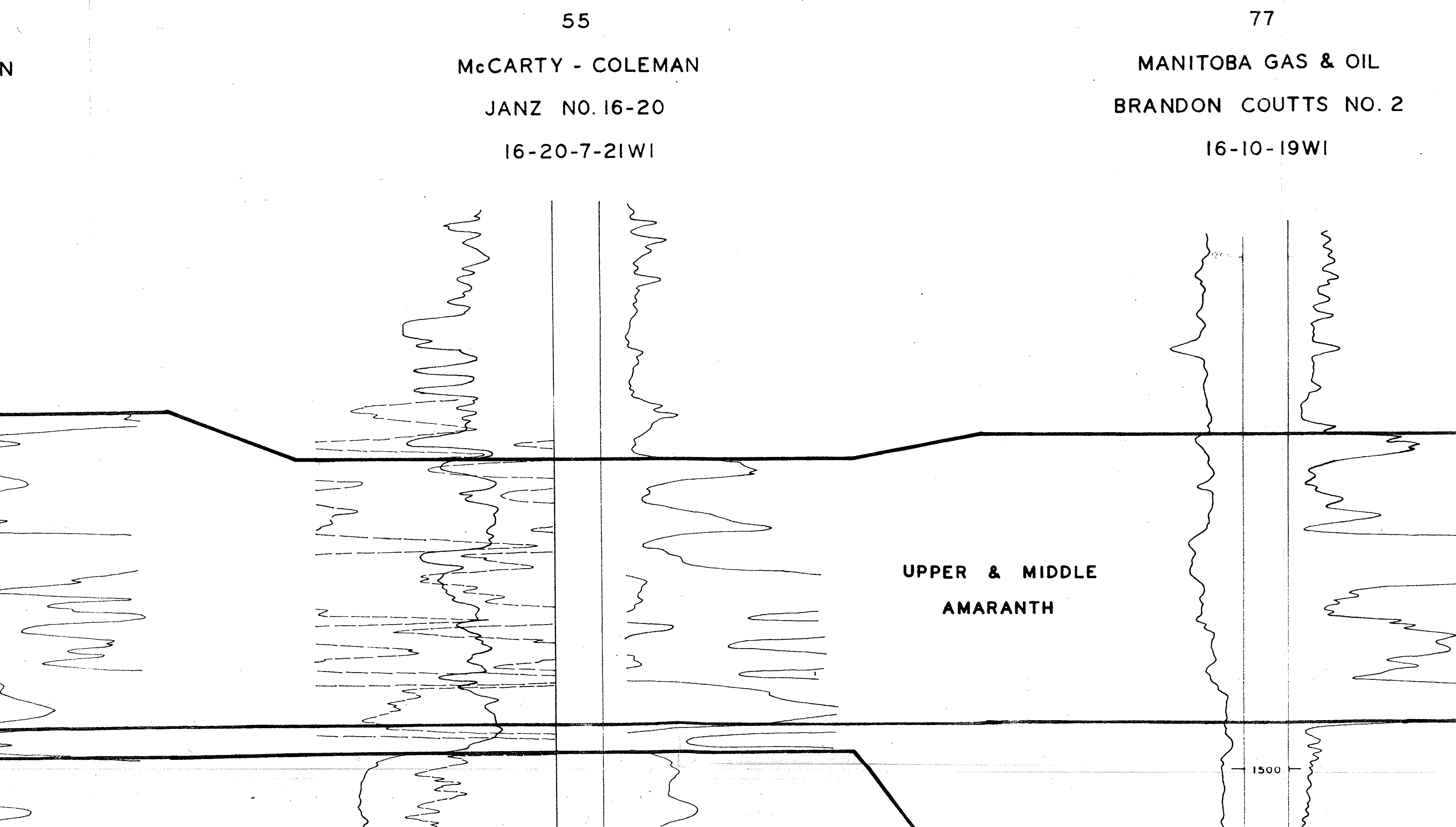
McCARTY - COLEMAN

MORRICE NO. 12-28

12-28-6-23WI

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McCARTY - COLEMAN
JANZ NO. 16-20
16-20-7-21W1
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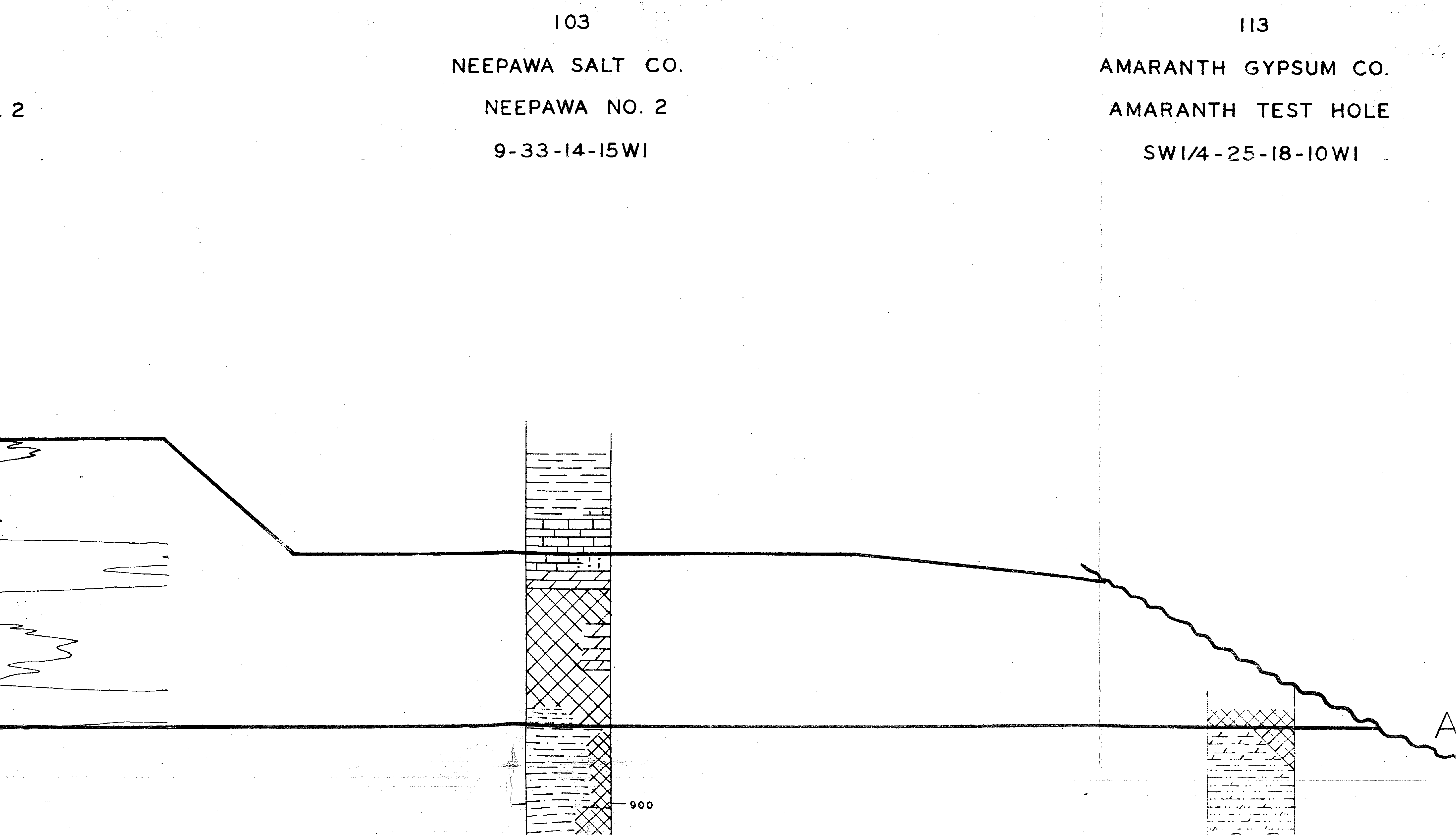
MANITOBA GAS & OIL
BRANDON COUTTS NO. 2
16-10-19W1
UPPER & MIDDLE
AMARANTH
1500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NEEPAWA SALT CO.
NEEPAWA NO. 2
9-33-14-15W1
113
AMARANTH GYPSUM CO.
AMARANTH TEST HOLE
SW1/4-25-18-10W1
900

103

NEEPAWA SALT CO.

NEEPAWA NO. 2

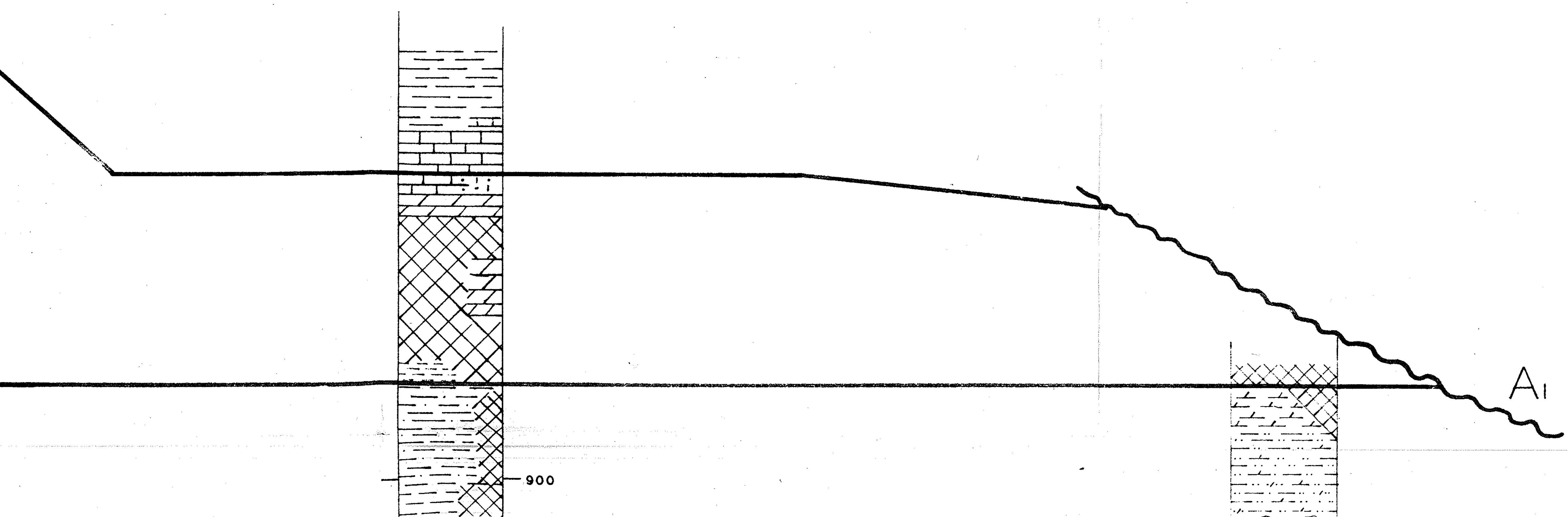
9-33-14-15W1

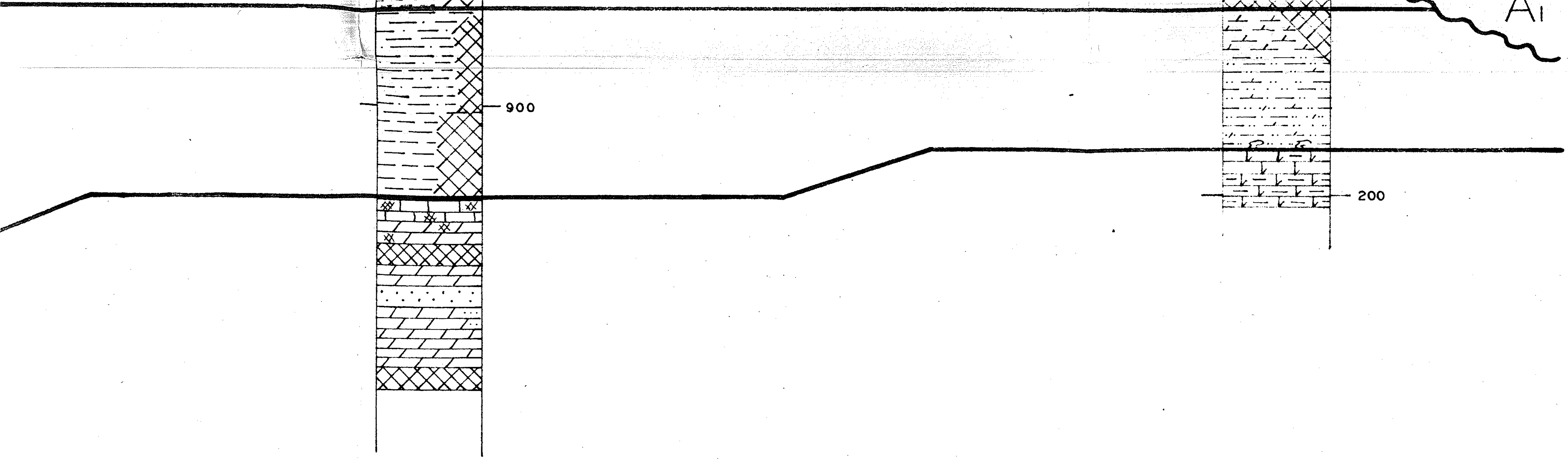
113

AMARANTH GYPSUM CO.

AMARANTH TEST HOLE

SW1/4-25-18-10W1

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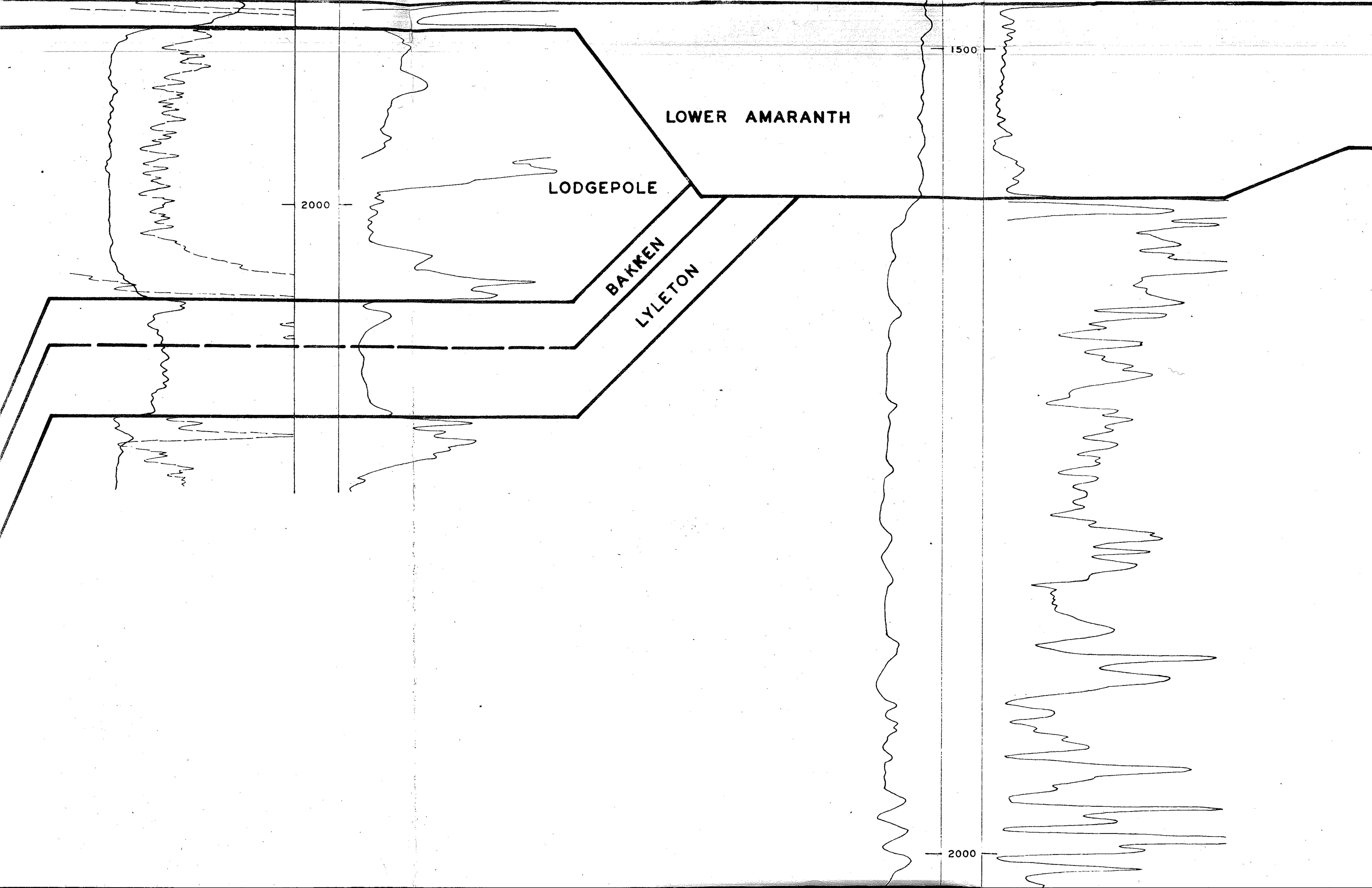
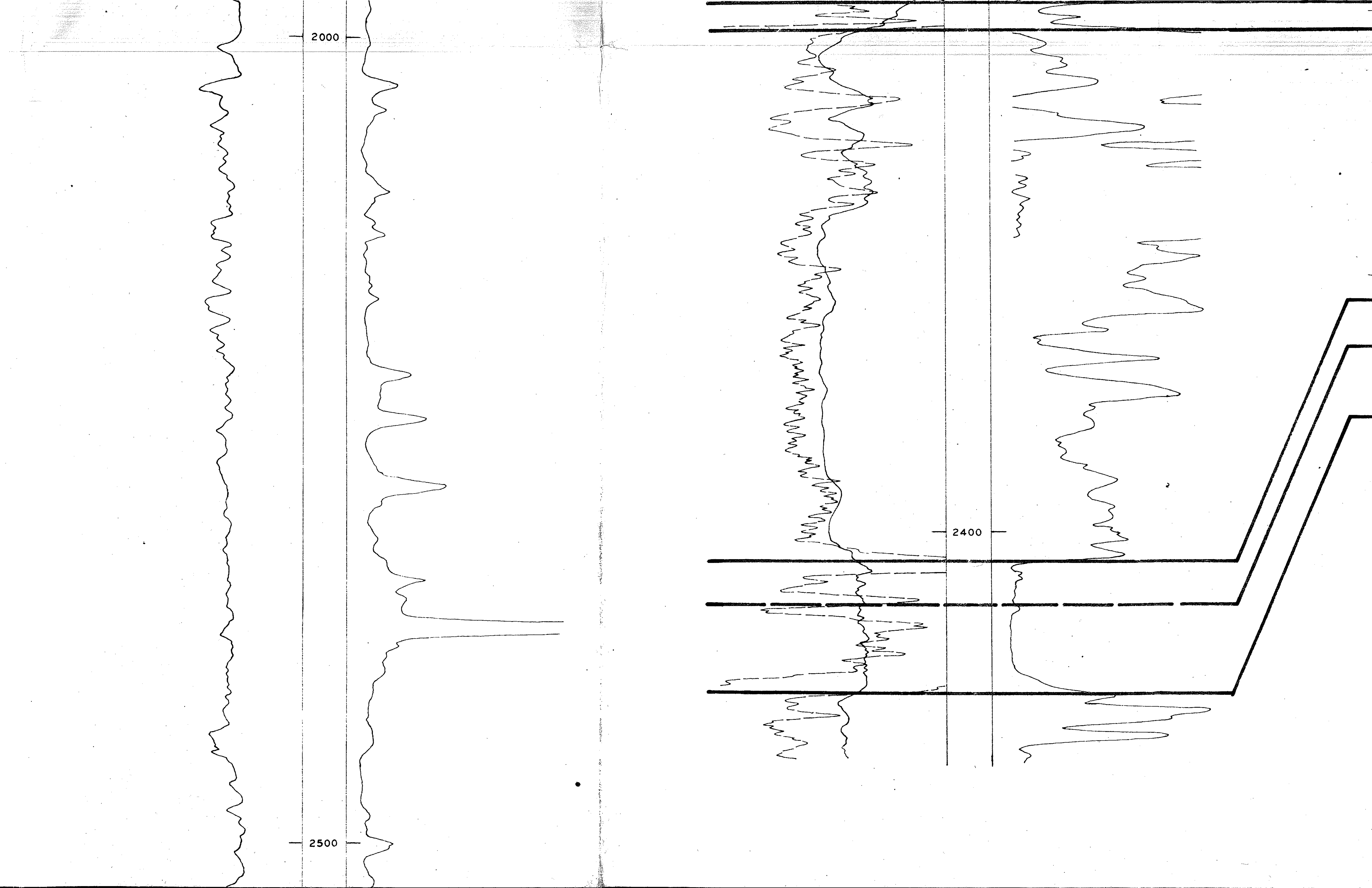
200
A1



LOWER AMARANTH
LODGEPOLE
BAKKEN
LYLETON
2000
1500
2000



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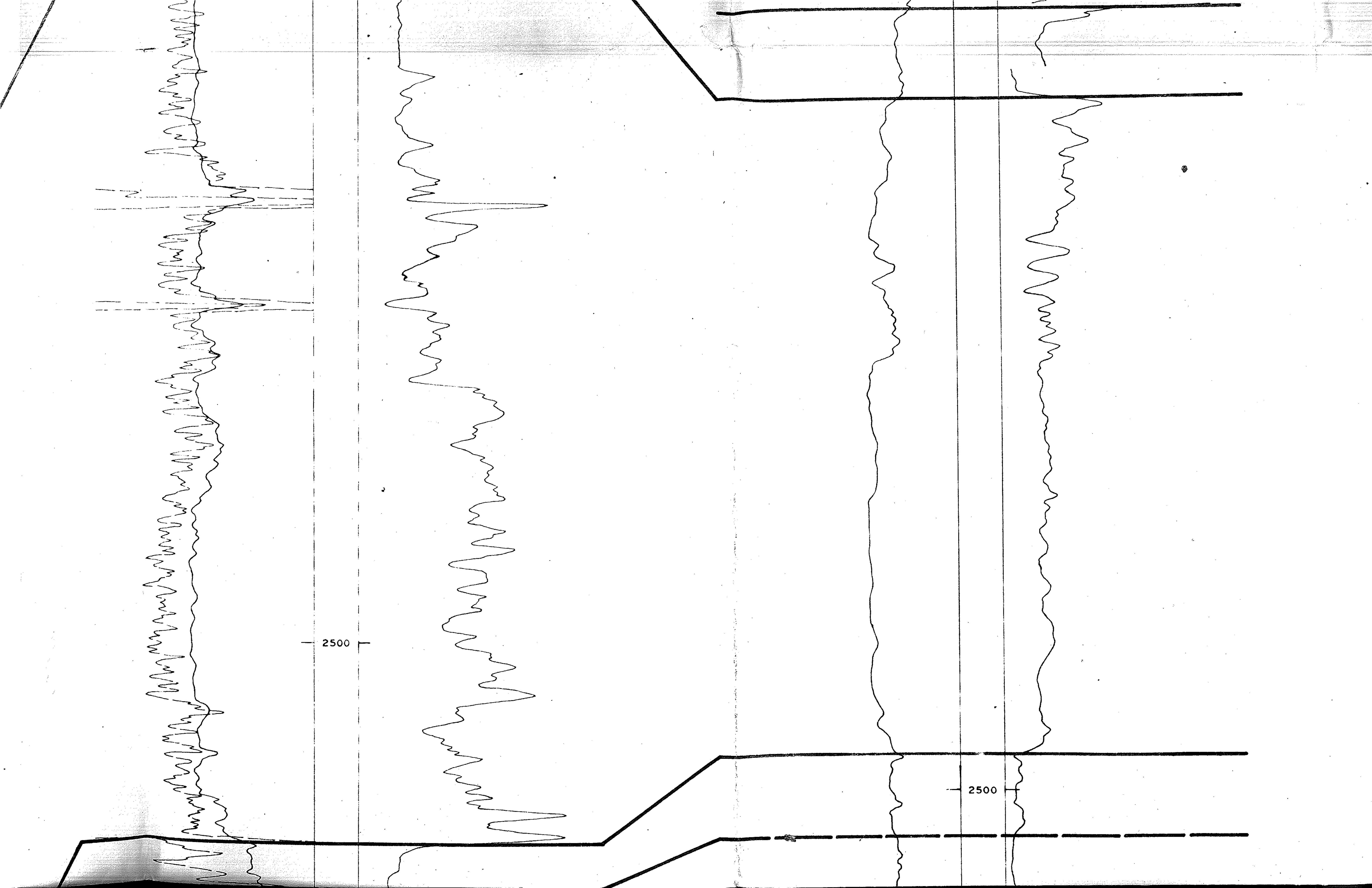
2500
2400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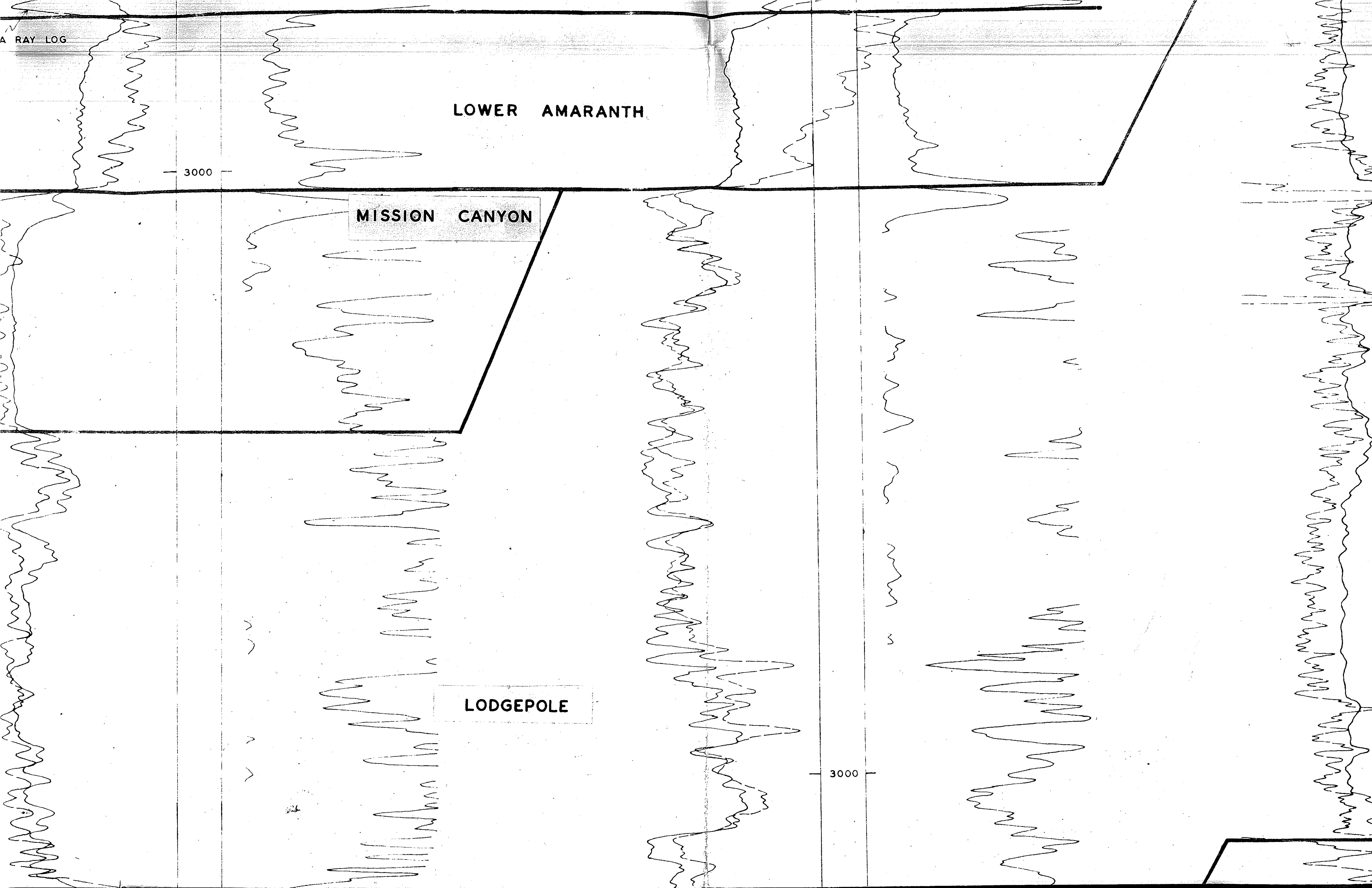
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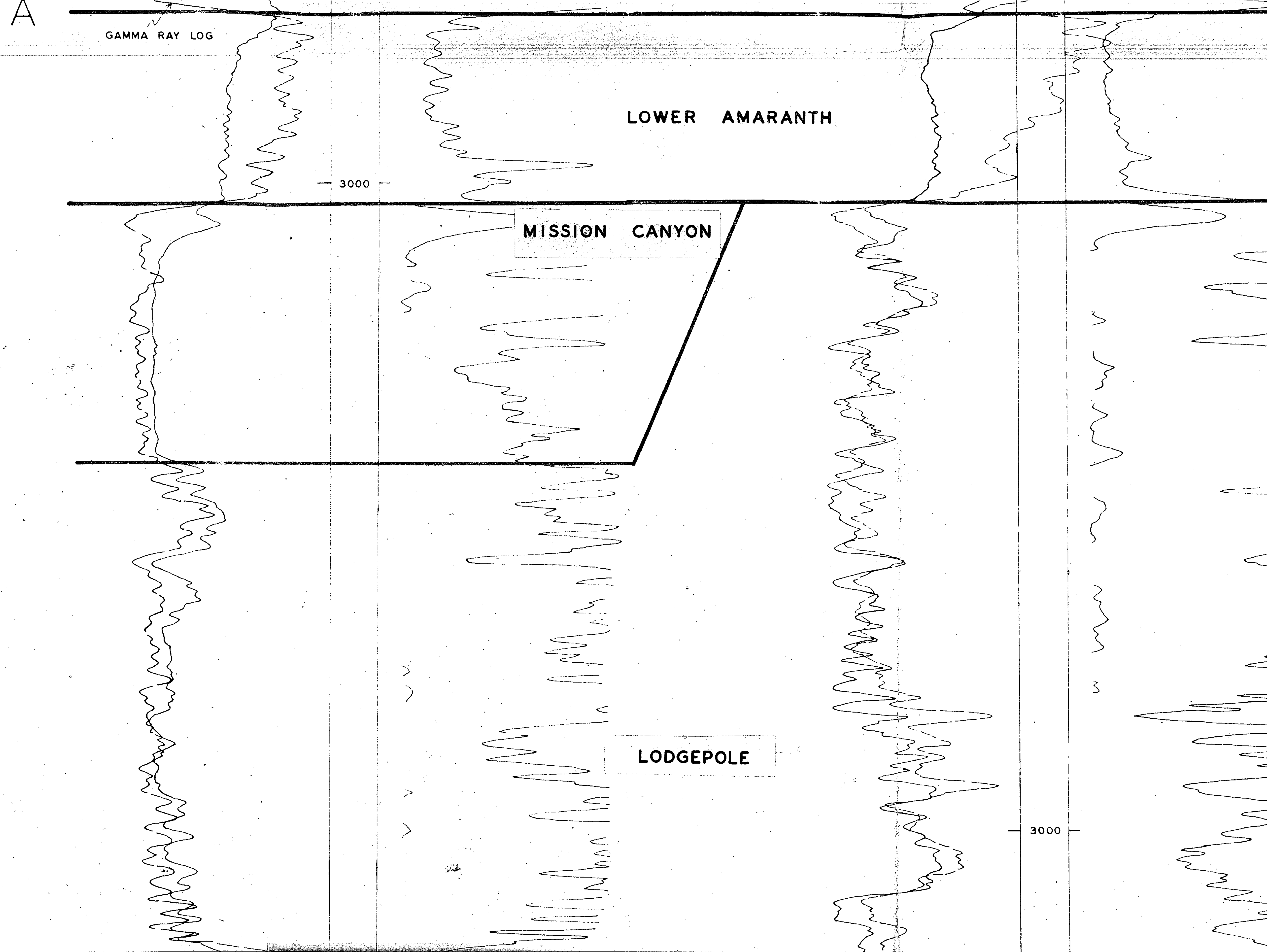
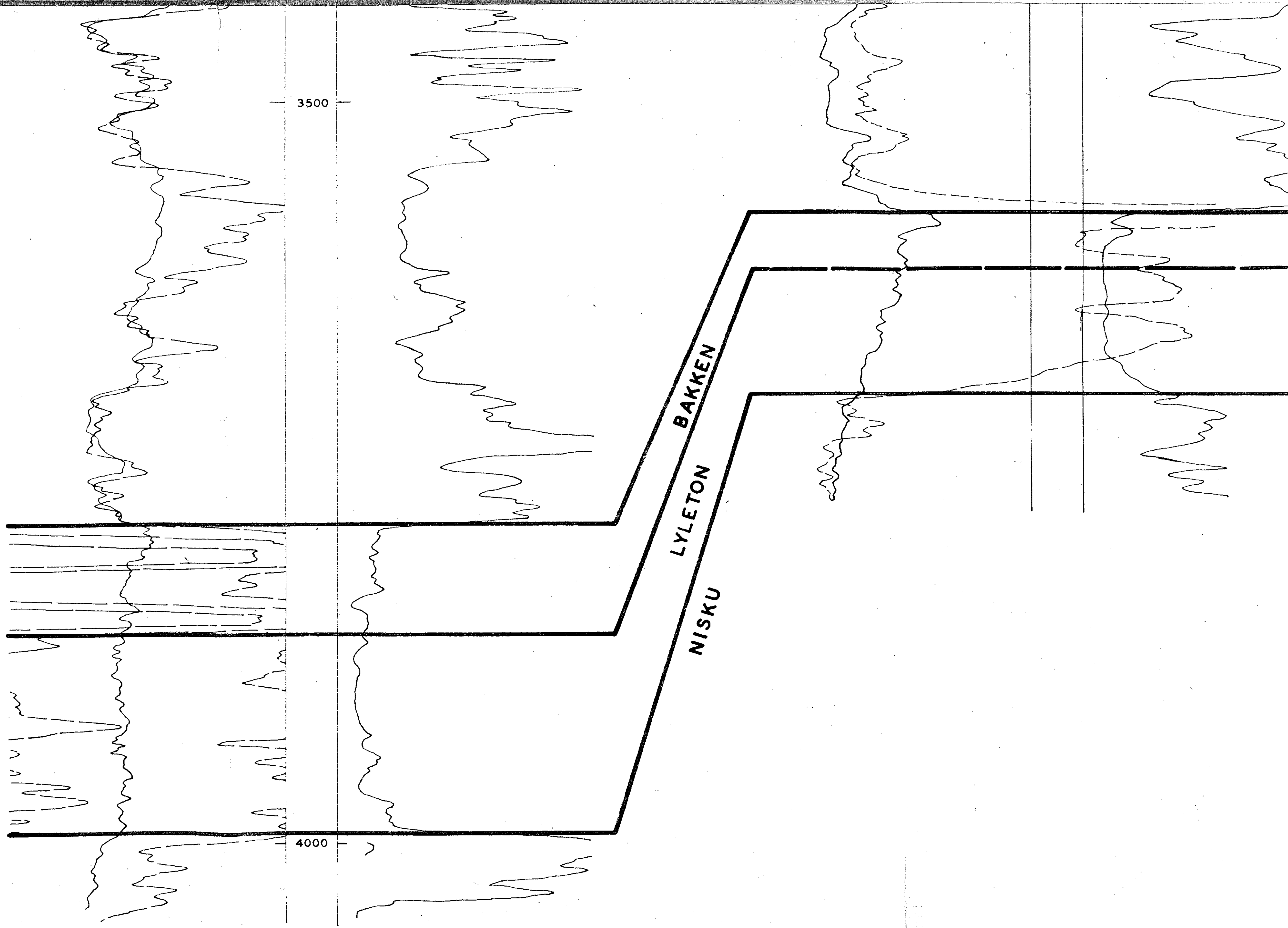
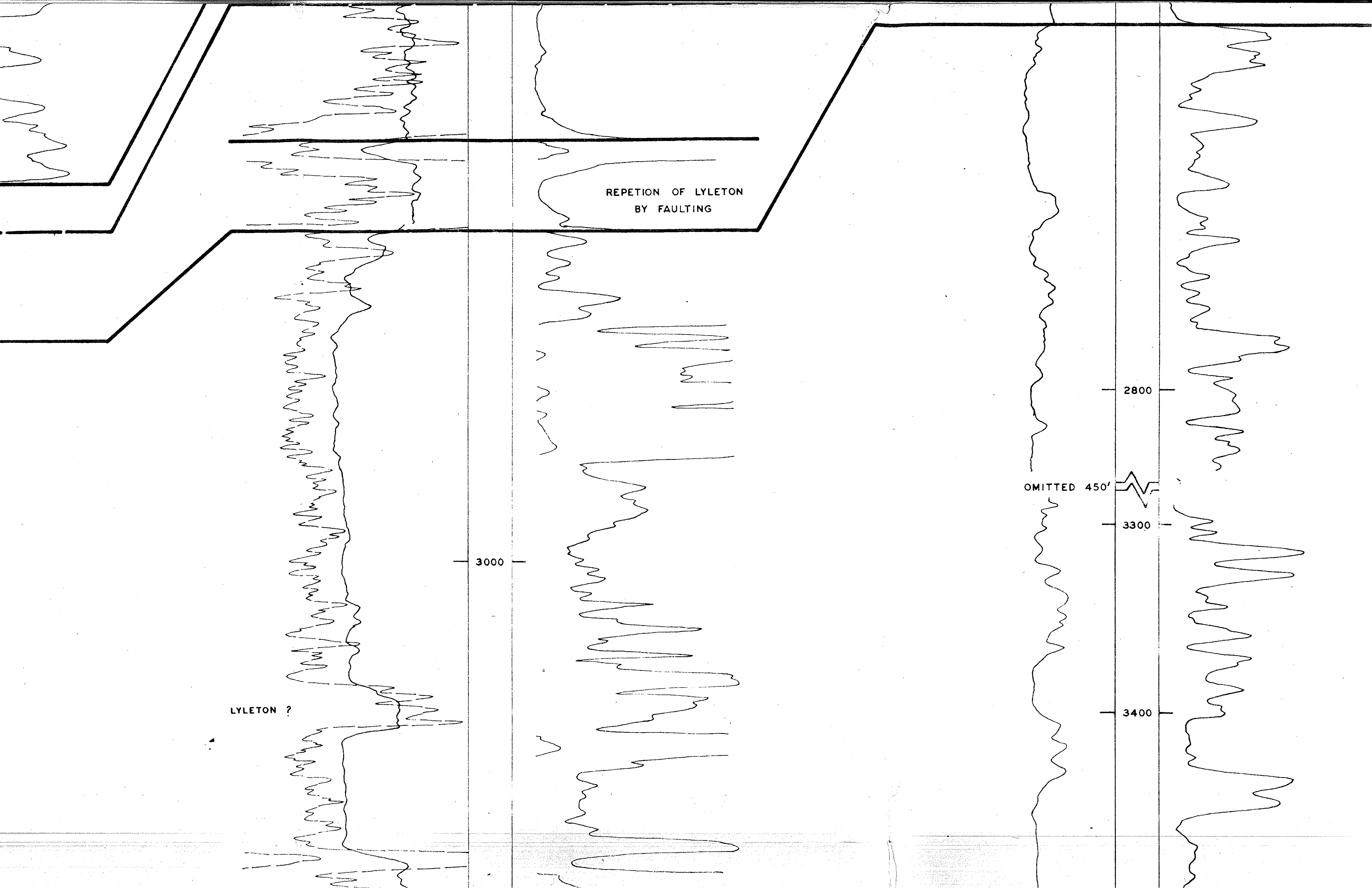
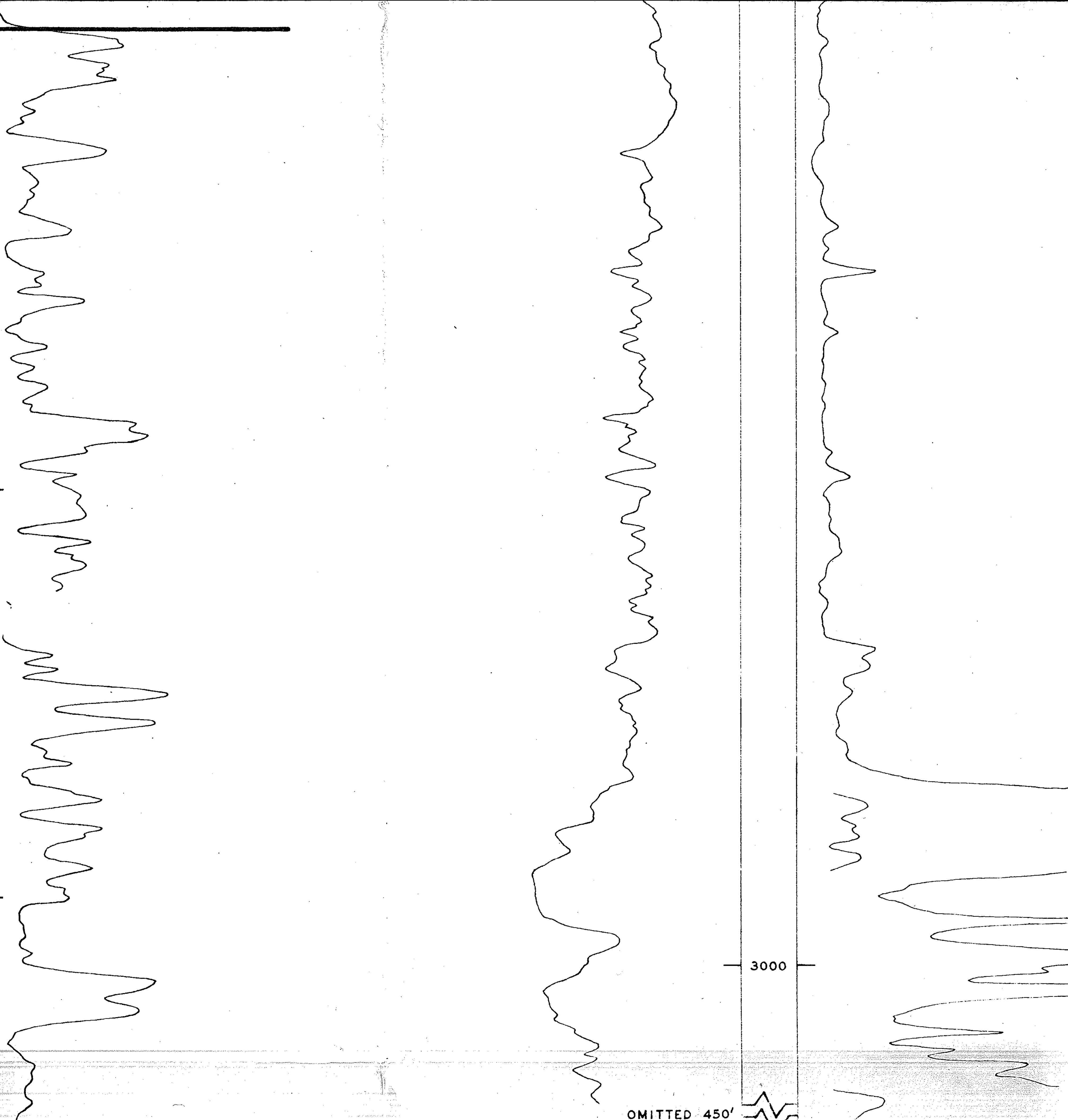
LOWER AMARANTH
3000
MISSION CANYON
LODGEPOLE
3000



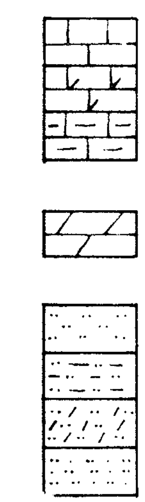
A
GAMMA RAY LOG
LOWER AMARANTH
3000
MISSION CANYON
LODGEPOLE
3000


3500
4000
BAKKEN
LYLETON
NISKU


REPETION OF LYLETON
BY FAULTING
LYLETON ?
3000
2800
OMITTED 450'
3300
3400



STRAT



HUGH R. Mc

PLATE 6.

STRATIGRAPHIC CROSS SECTION A–A1.

LEGEND

LIMESTONE
dolomitic
argillaceous

DOLOSTONE

SILTSTONE
argillaceous
dolomitic
sandy

SHALE
silty
sandy
dolomitic

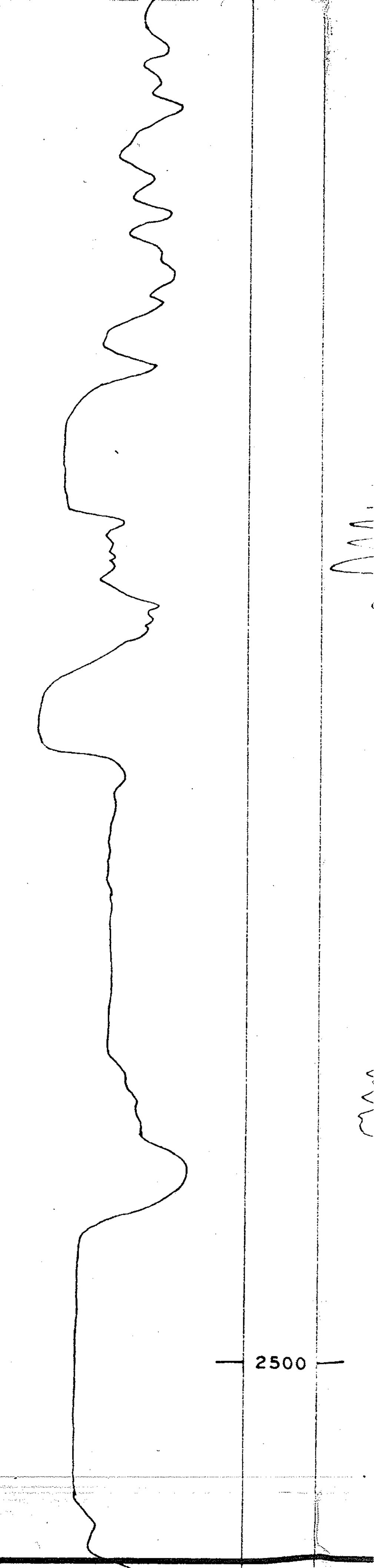
ANHYDRITE & GYPSUM

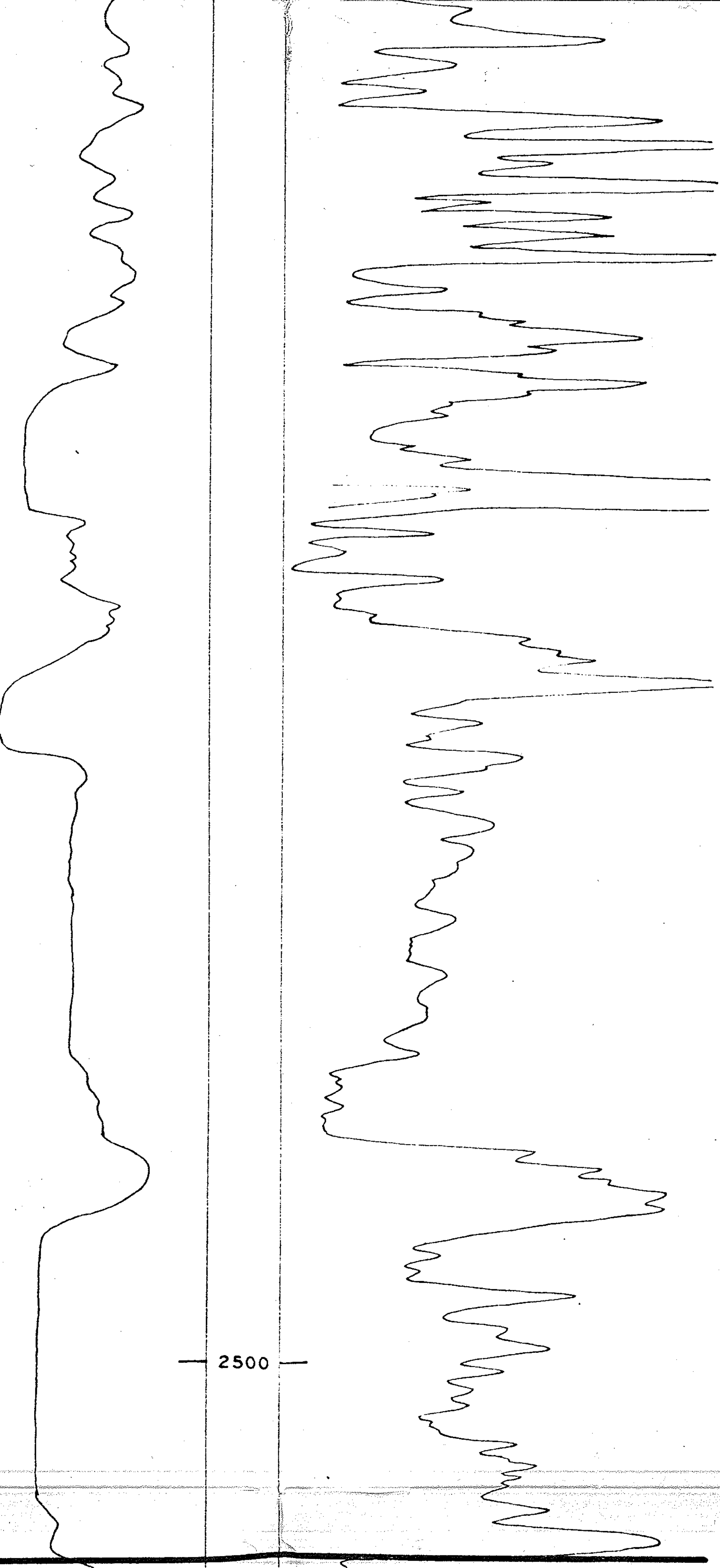
BRECCIA

SANDSTONE

HUGH R. McCABE

SEPTEMBER 1955

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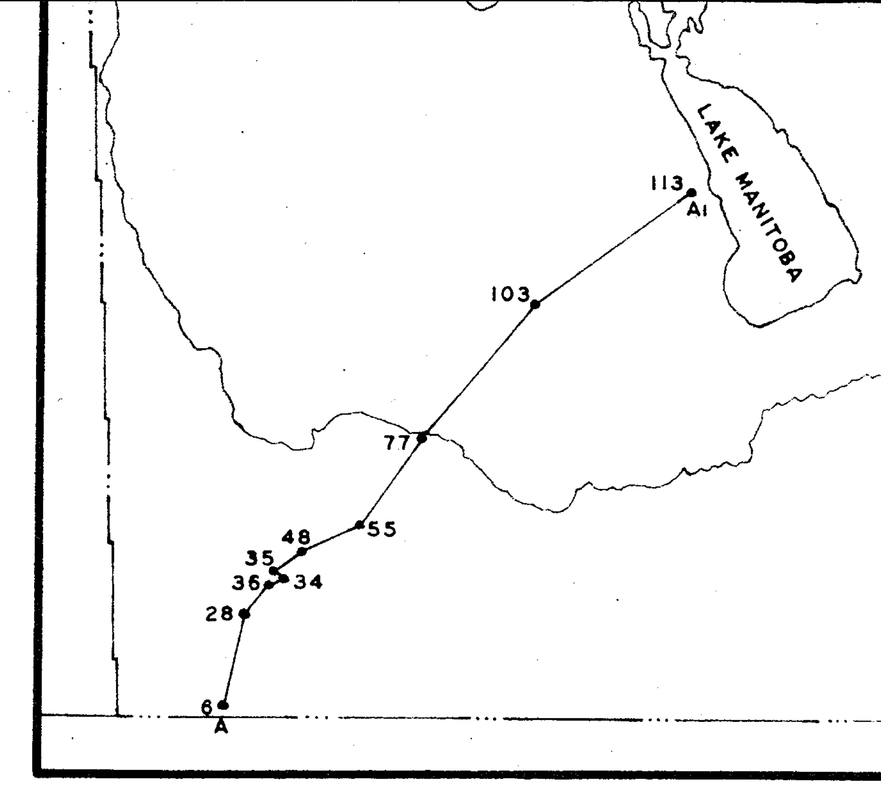
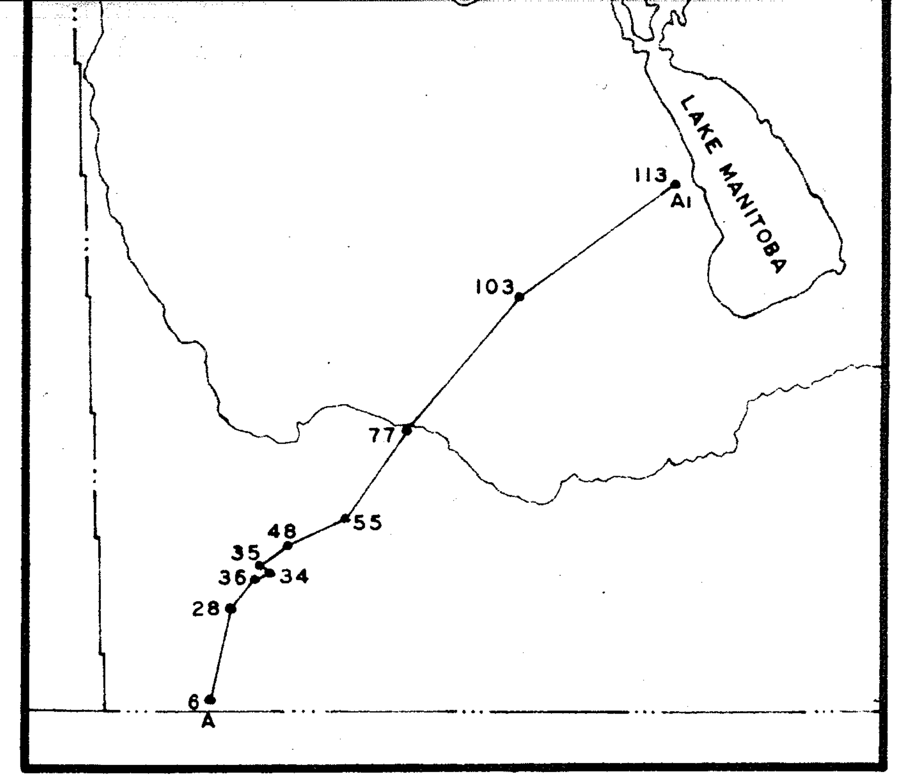
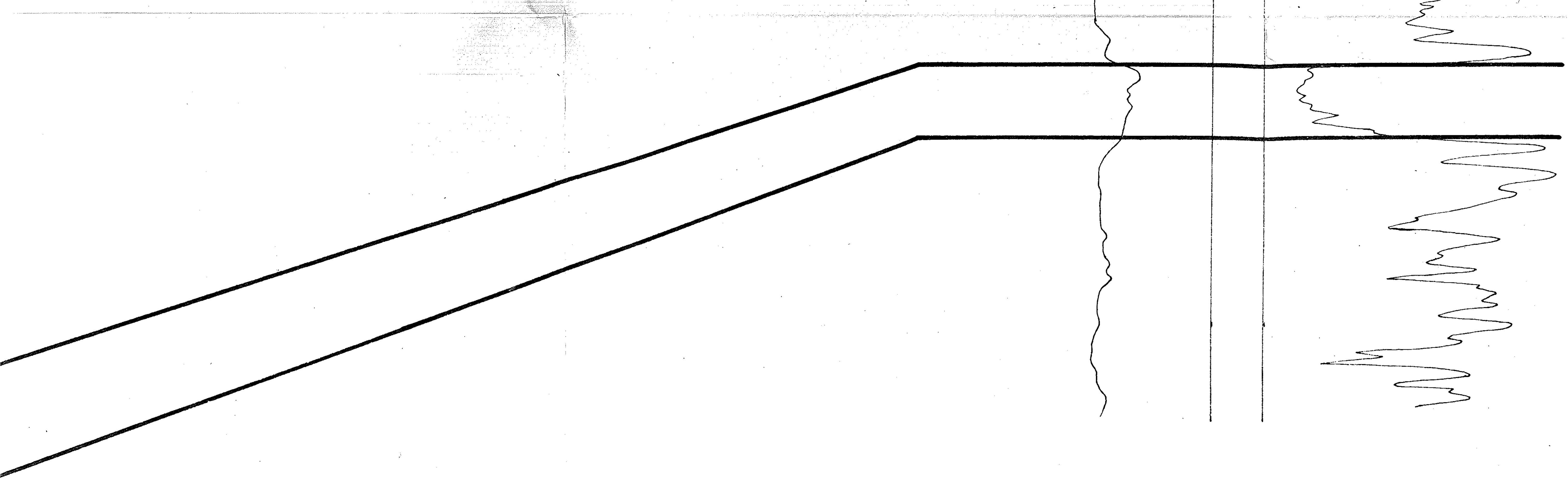
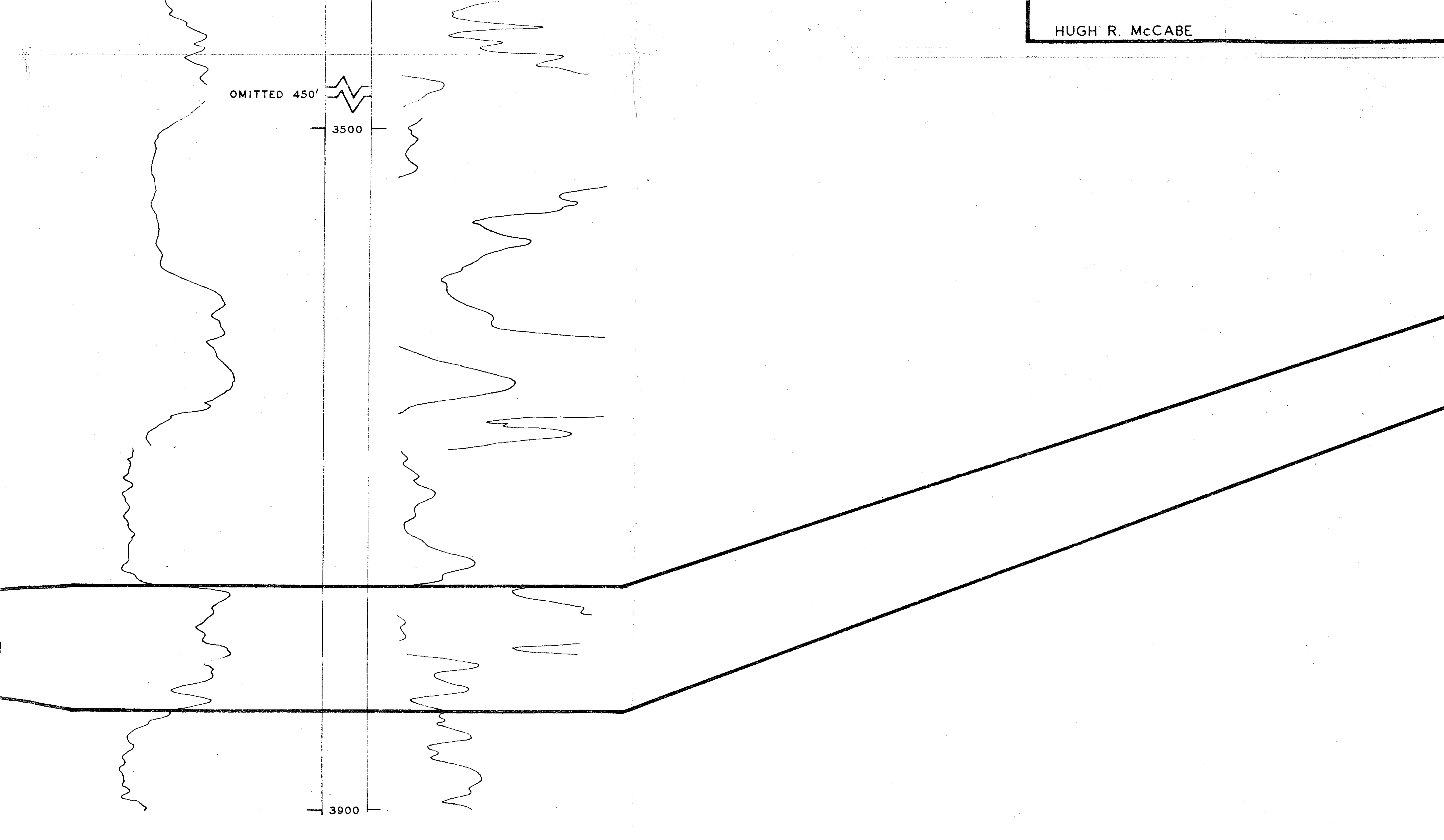
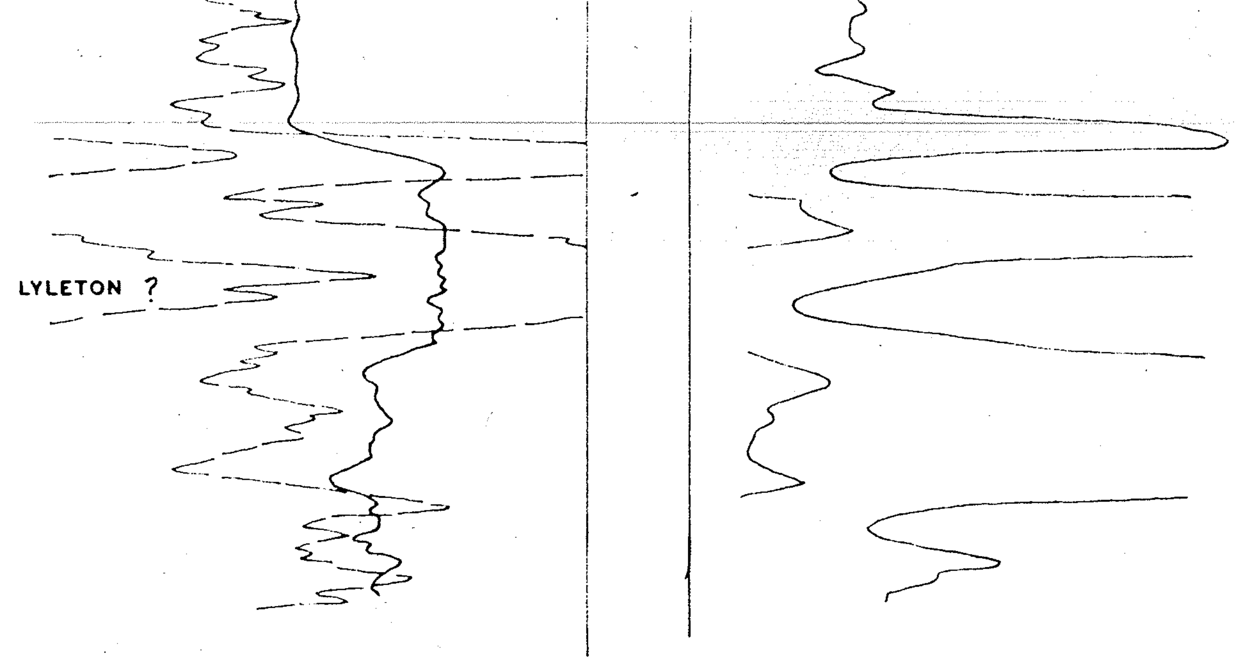

LAKE MANITOBA
113
A1
103
77
55
48
35
36
34
28
6
A


LAKE MANITOBA
113
A1
103
77
55
48
35
36
34
28
6
A

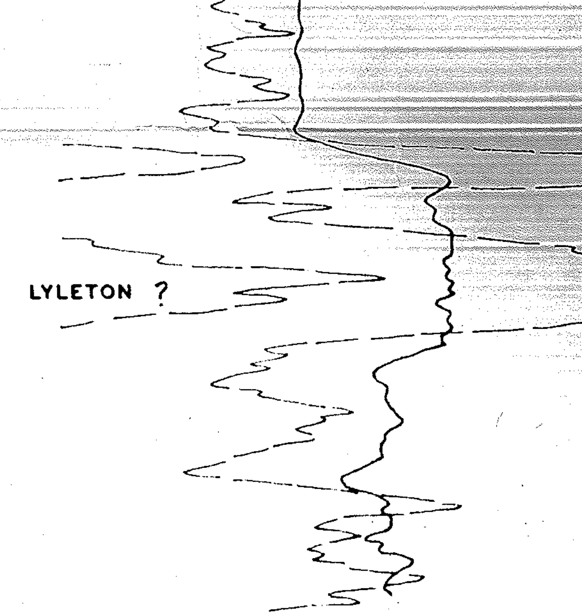
SEPTEMBER 1955




HUGH R. McCABE
OMITTED 450'
3500
3900



NOTE : WELLS NO. 34, 35, 36 ARE LOCATED ON OR PERIPHERAL TO THE HARTNEY STRUCTURE AND NO CORRELATION IS POSSIBLE BETWEEN THESE WELLS IN THE AMARANTH INTERVAL.



NOTE : WELLS NO. 3
PERIPHERAL
AND NO CO
THESE WELL