North Dakota Geological Survey

WILSON M. LAIRD, State Geologist

Report of Investigation 43

A Look at the LOWER and MIDDLE MADISON of Northwestern North Dakota

by

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and S. B. ANDERSON

GRAND FORKS, NORTH DAKOTA

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ABSTRACT

Facies changes noted within the lower and middle Madison suggest the possibility of stratigraphic traps in this interval in northwestern North Dakota. These include changes from "clean" carbonates to argillaceous carbonates, fine grained carbonates to finely crystalline, dense carbonates, and normal marine carbonates to silicified carbonates. Limited control hinders delineation of such traps at present, but future deep exploration should consider such lower and middle Madison possibilities.

INTRODUCTION

As of January 1, 1966, Madison reservoirs were credited with about 81 per cent of the recoverable crude oil reserves of North Dakota (Folsom, 1966, p. 9). Other reserves were credited as follows: Devonian reservoirs about 13 per cent, Silurian reservoirs about 2 per cent, and Ordovician reservoirs about 1 per cent. The statistics in part reflect the emphasis that has been placed on exploration for Madison reservoirs which stratigraphically are in the middle to upper part of the Madison Formation. Exploration emphasis has been encouraged by success in finding Madison reservoirs, and at relatively shallow depths.

The present study is concerned with potential reservoirs in the lower part of the Madison Formation, with particular attention to northwestern North Dakota where a recent test has shown some potential for commercial production. The area of study (fig. 1) is about 5,600 square miles. In this area there have been only 79 wells penetrating the complete Madison Formation; 47 of them are within the Beaver Lodge

Field and only 14 are located away from the Nesson anticline. Altho, there are wide areas where little or no information is available, the information that is available indicates some interesting facies changes within the lower Madison Formation. These changes seem to merit more attention than has previously been given to this stratigraphic interval. The purpose of the present study is to point out some of these facies changes so that future exploration for Devonian, Silurian, and Ordovician reservoirs will also consider some of the lower and middle Madison possibilities.

The present study is of a reconnaissance nature. Samples of the Calvert-Cater No. 1 well (fig. 4) were examined, but other lithologic interpretations are based on North Dakota Geological Survey Circular descriptions. In this area, Circular descriptions are available for fourteen wells which penetrated lower Madison rocks.

STRATIGRAPHY

History of Nomenclature

Terminology applied to the Mississippian rocks of the Williston Basin is a combination of subsurface terminology of this area, and the terminology applied to these rocks in their outcrop areas in Montana. The subsurface terms have been introduced because of difficulties in extending surface terminology into the subsurface and because of the need to more adequately define facies relationships of the Madison in the subsurface. There has also been a host of "pay zone terms" applied to various porous intervals by petroleum geologists, but these are informal terms with no formal stratigraphic standing.

The term Madison Limestone was first used by Peale (1893, p. 33) for the "Lower Carboniferous limestones" exposed near Three Forks, Montana. Collier and Cathcart (1922, p. 173) divided the Madison Limestone of the Little Rocky Mountains, Montana, area into two formations, the Lodgepole (lower) and Mission Canyon (upper) Formations, elevating Madison to the rank of group. This terminology was extended into the subsurface, where Seager (1942, p. 864) introduced the term Charles Formation for some evaporite beds present between the Madison Limestone and the overlying Big Snowy Group in the California Company - Charles No. 4 well, located in eastern Montana. Seager was uncertain whether he should include the Charles in the Madison or Big Snowy Group, but chose to include it as the basal member of the Big Snowy Group. Perry and Sloss (1943) followed this suggestion and this practice was generally followed until 1951 when the Charles Formation was transferred to the Madison Group (Laird and Towse, 1951) because the increased amount of subsurface information then available showed that the Charles was genetically related to Madison rather than Big Snowy deposition.

Facies changes within the Madison in the subsurface has led to many difficulties of correlation in extending the surface terminology through the subsurface of the Williston Basin. A practical solution to these problems was devised by Fuller (1956), who used mechanical-log marker horizons for subdivision of the Madison strata in southeastern Saskatchewan. In that area the Madison consists of alternating carbonates, evaporites and fine-grained clastics. Fuller reasoned that these relatively thin beds, persistent over wide areas, must be nearly time-parallel units, and he used the term "Beds" for these para-time-rock units. His marker horizon concepts, but not his original units, were used by the Saskatchewan Geological Society (1956) when they divided the Madison of Saskatchewan and defined these units in ascending order as: Souris Valley, Tilston, Frobisher - Alida, Midale, Ratcliffe and Poplar Beds.

The marker horizons used for subdivision of the Madison strata in southeastern Saskatchewan are recognizable in north-central North Dakota, and a similar terminology could be used in this area. However, for basin-wide correlations, only two good marker horizons have so far been recognized within the Madison and these marker horizons do not coincide with marker horizons chosen for subdivision of the Madison in Saskatchewan. Rather, one is within the Poplar Beds and one is within the Midale Beds.

Smith (1960) used these two good marker horizons for subdivision of the Madison in North Dakota. He redefined the Saskatchewan terms, rather than introduce new terms, redefining the Poplar, Ratcliffe and Frobisher - Alida units, dropping the term Midale, and replacing the term Souris Valley with the term Bottineau. Since the Stratigraphic Code does not recognize para-time-rock units, he referred to these units as intervals, rather than Beds. Unfortunately, his full report was never published, so one must go to Anderson and others (1960, p. 4) to find the log characteristics of the two good marker horizons as well as a comparison of the redefined intervals with the previously defined Beds.

As redefined by Smith, the two good marker horizons mark the base of the Poplar and Ratcliffe intervals (fig. 2). On the eastern flank of the basin the Frobisher - Alida, Tilston and Bottineau intervals can also be recognized, but the marker horizons by which they are

Figure 1 – Location map showing area of study, wells in area that penetrate lower Madison rocks, and lines of cross section.

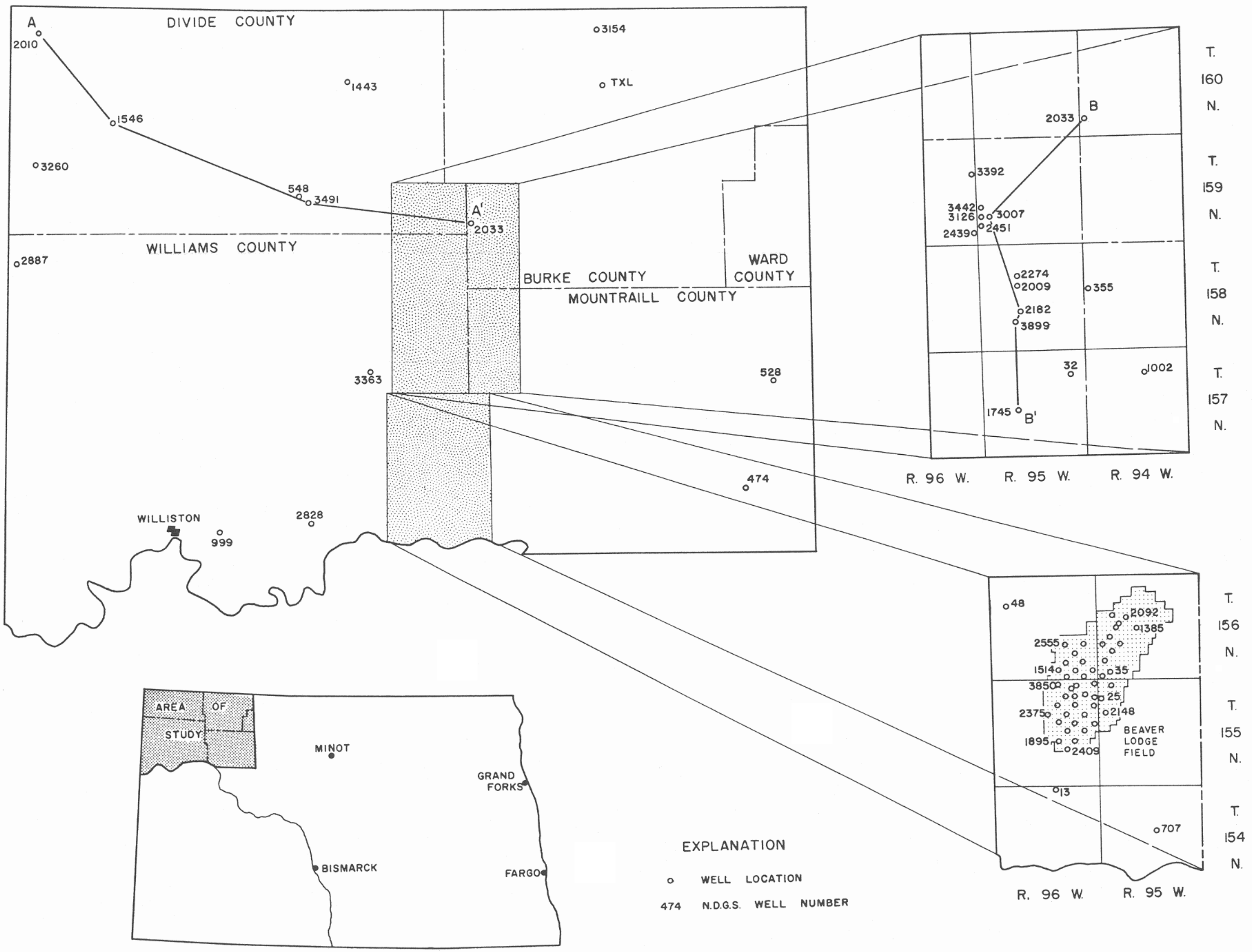


Figure 2 – Typical log of Madison Formation showing subdivision into units, intervals and subintervals.

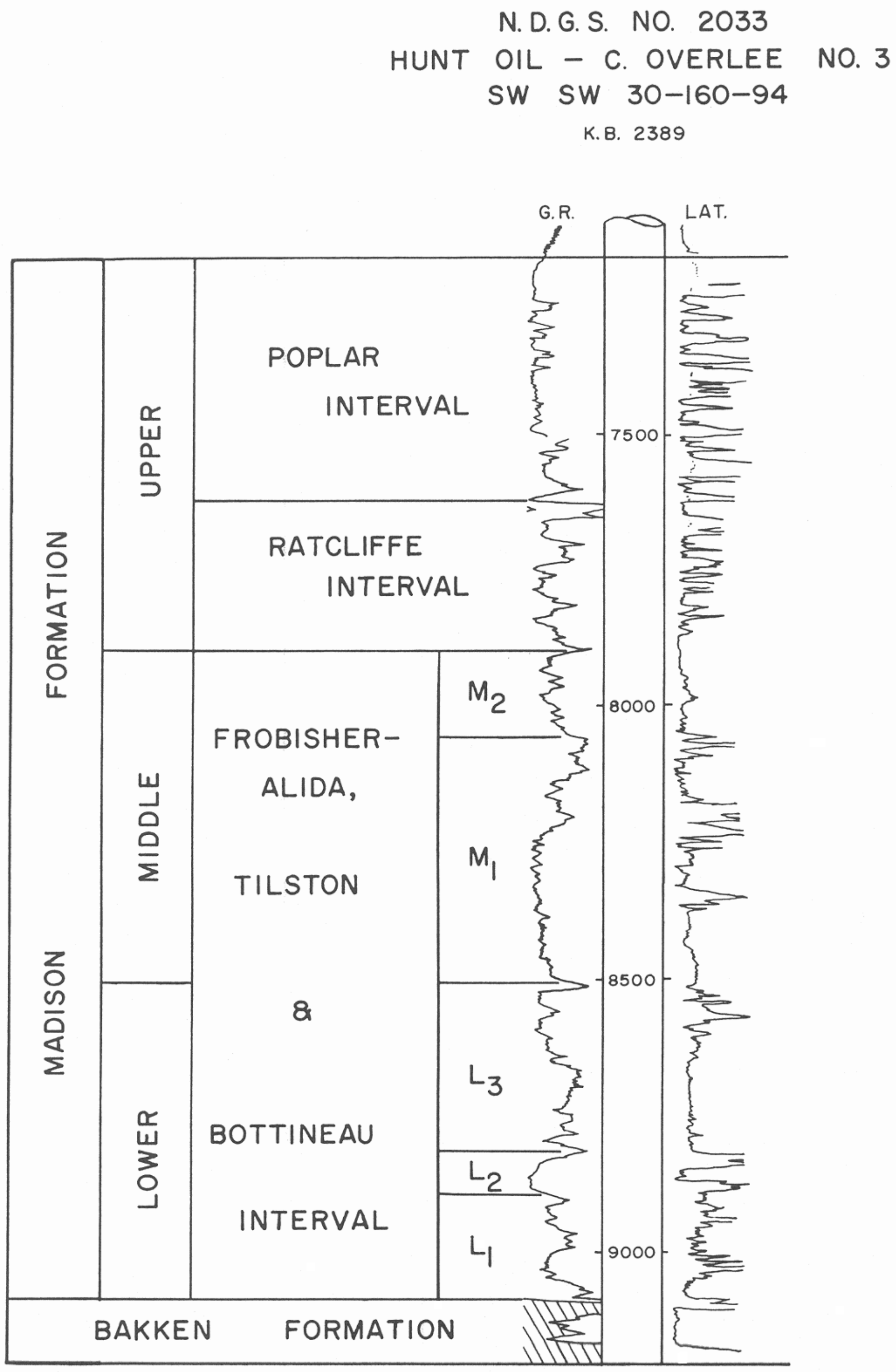


Figure 3 — Cross Section A-A'.

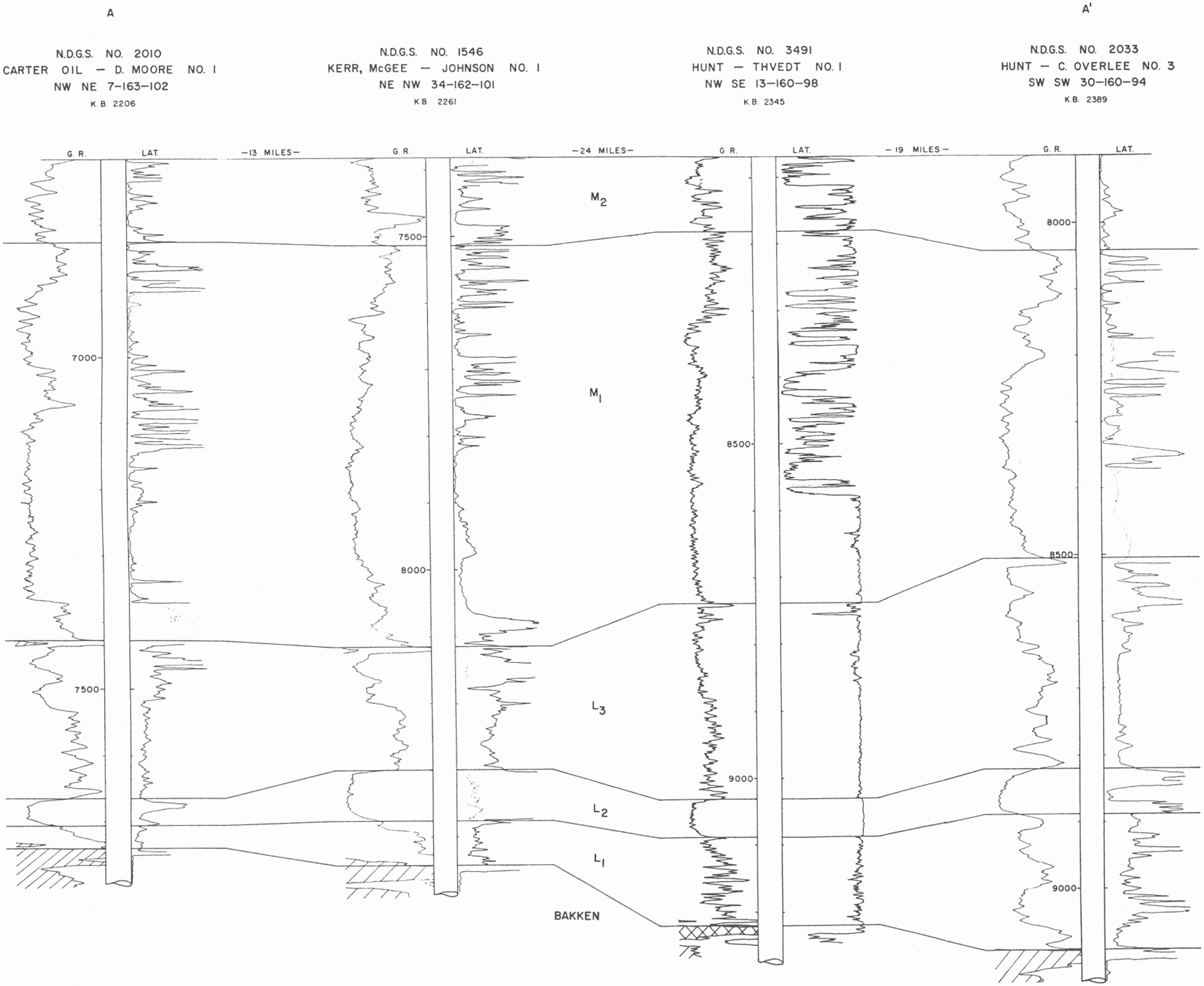
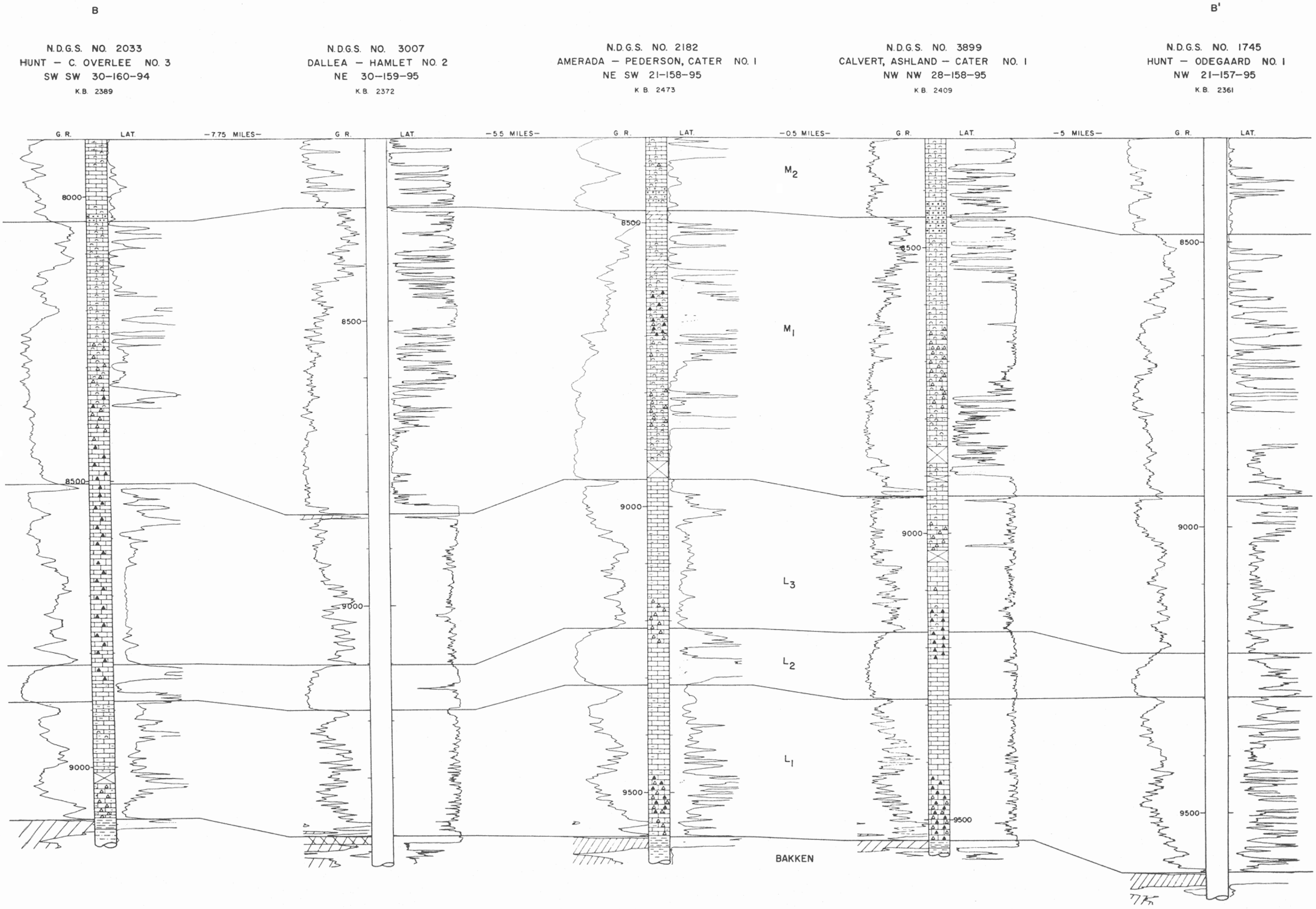


Figure 4 - Cross Section B-B'.



recognized cannot yet be traced into the central basin area. Therefore, in the area of this study, the stratigraphic interval included on the cross section (figs. 3, 4) includes all of the Frobisher-Alida, Tilston and Bottineau intervals, but boundaries between these intervals have not been drawn.

The Poplar and Ratcliffe intervals are herein referred to as upper Madison. There is another "good gamma ray marker" lower in the Madison in the area of study (fig. 2) which is herein used to divide the remainder of the Madison into lower and middle units. Cross sections show that there are also some less persistent gamma ray markers within the lower and middle units; these markers provide a basis for subdivision of the lower and middle units into informal subintervals. These subintervals are herein referred to as, in ascending order: L_1, L_2, L_3, M_1 and M_2 subintervals. The cross sections also show that there are many log variations within the lower and middle Madison, some of which suggest the possibility of stratigraphic traps within these subintervals.

Lower Madison

General Statement:

The lower Madison has generally been described as a siliceous or cherty, usually dense, limestone. It drills slowly and has not been the focus of much interest as a possible reservoir rock. Sparsity of well control has hindered recognition of facies changes within the lower Madison, but Devonian and deeper exploration is now providing information necessary for a review of previous ideas concerning reservoir possibilities of the lower Madison. Of particular interest is the "porosity zone" developed within the L_2 subinterval in the area of the Hunt, Amerada - Pederson, Cater No. 1 well (fig. 4), where oil shows were reported from this zone, and the Calvert - Cater No. 1 well (fig. 4), where oil has been recovered from this zone on production tests. Further studies of the lower Madison subintervals may point up other potential prospects.

L_1 subinterval:

The L_1 subinterval ranges in thickness from about 35 feet in the Carter - D. Moore No. 1 well (fig. 3) in the northwestern part of the area of study to about 300 feet in the Hunt - Odegaard No. 1 well (fig. 4). The log characteristics suggest that this subinterval might be an argillaceous or "dirty" limestone unit. Some sample descriptions note some argillaceous limestone, but most of the samples have been described as finely crystalline, dense limestone. Samples of the lower part of this subinterval have usually been described as a finely crystalline, siliceous and cherty limestone; "siliceous" refers to a siliceous residue left when the limestone is dissolved in acid, while "cherty" refers to free chert.

This subinterval thins northwestward. The thinning, as can be seen on the cross section (fig. 3), appears to be from the base upward suggesting that the thinning is due to non-deposition toward the basin flank. Present well control does not reveal any well defined porosity changes within this subinterval which might be pointed to as good potential stratigraphic traps, but the variations in thickness, probably due to non-deposition, provide conditions which might be favorable for such traps.

L_2 subinterval:

The L_2 subinterval is generally 80 to 100 feet thick in this area. Log characteristics of this subinterval suggest a "clean" carbonate unit. Sample descriptions of the upper part describe it as finely crystalline, siliceous or cherty limestone and describe the lower part as finely crystalline, dense limestone. In some wells there is as much as 20 feet of fine grained limestone, with fair to good porosity, near the middle of this subinterval.

This porous zone was first noted in the Hunt, Amerada - Pederson, Cater No. 1 well (fig. 4), where samples of the granular limestone from the interval 9240 to 9260 feet were oil stained and chips did cut with carbon tetrachloride; the zone was not tested, however. In the Calvert - Cater No. 1 well (fig. 4), the interval from 9225 to 9240 feet was logged as fine grained, granular limestone, but none of our samples contained either oil stain or would cut with carbon tetrachloride. The operator did, however, run a wireline test at 9223 with the following results: shut in 8 minutes, open 40 minutes, shut in 15 minutes; recovered 6250 cc salt water with a scum of oil, SIP 4200 - 4200#, HP 5100#. Casing was set in this well and the interval from 9221 to 9226 feet was perforated with 3 shots and acidized with 500 gallons of MCA. Operator then swabbed 3/4 barrel of oil per hour for 8 hours. It then flowed 29 barrels of oil in 5 hours. Operator then acidized with 2,000 gallons of CRA acid. The well then flowed 25 barrels of oil and 50 barrels of acid water in 7 hours. It then flowed 55 barrels of oil with a trace of water in 6 hours. The well was then completed higher in the Madison and the perforations in the L_2 subinterval have been shut in.

Areal distribution of the L_2 porous zone is unknown. It is well developed in the Hunt - Overlee No. 3 well (fig. 4). It is also well developed in the Hunt, Amerada - Pederson, Cater No. 1 well (fig. 4). Wells in the vicinity of the Pederson, Cater No. 1 well generally show some porosity in this subinterval, but it appears to be variable from well to well. It appears to pinch out toward the south, where none of the wells in the Beaver Lodge field show this porous zone in the L_2 subinterval. It also appears to pinch out updip to the northwest (fig. 3), where the wells in Burke and Divide Counties do not show any porosity development in the L_2 subinterval.

L_3 subinterval:

The L_3 subinterval is variable in thickness, ranging from about 300 feet in the Nesson anticline area to about 190 feet in the Kerr McGee - Johnson No. 1 well (fig. 3). Log characteristics also indicate considerable lithologic variability within this subinterval. Generally the upper 50 to 100 feet appears to be relatively "clean" carbonate, whereas the remainder appears to be interbedded "clean" and "dirty" carbonates. Sample descriptions generally describe this unit as finely crystalline, dense limestone, sometimes as siliceous or cherty, and rarely as argillaceous.

There are no readily apparent porous zones within the L_3 subinterval in the area of study. However, the thickness variations, particularly within the upper "clean" carbonate section suggest that porous zones similar to that found in the L_2 subinterval might be developed somewhere within the L_3 subinterval. This possibility should be considered in future exploration.

Middle Madison

General Statement:

The middle Madison has been the primary objective during development of the Madison reservoirs along the Nesson anticlinal trend. While these reservoirs are primarily structural accumulations, there are some log variations within the middle Madison suggesting that porosity - permeability changes may be a contributing factor.

Gamma ray characteristics of the middle Madison make further subdivision into subintervals difficult and somewhat arbitrary. It might be divided into three or more subintervals, but for purposes of this study only two are recognized, the M_1 and M_2 subintervals. The top of the M_1 subinterval has been placed at the top of a zone of relatively high gamma ray readings. The top of the M_2 subinterval is marked by a gamma marker which has often been referred to in exploration work as "top of main pay" or "Nesson pay." The M_1 subinterval is a good reservoir rock in some fields, particularly in the area south of the Missouri River, where the upper part of this subinterval is productive; however, the M_2 subinterval has been the main producing zone.

M_1 subinterval:

This subinterval is about 450 to 500 feet thick and consists mainly of carbonates with some chert. Samples of this subinterval are usually described as finely crystalline, dense or fine grained, fragmental, fossiliferous limestone. The upper part is locally dolomitic and argillaceous. The middle and lower parts are commonly siliceous or cherty. The chert is commonly fossiliferous, oolitic, or pelletoidal, suggesting preservation of original carbonate primary structures through secondary processes of silicification. Where silicification has occurred, it is commonly accompanied by very high resistivity readings on the laterolog. This is not to suggest that all "tight zones" on the laterolog indicate this secondary silicification, but the possibility should be investigated.

There are several instances where these "tight zones" due to silicification are known to be present in the middle and lower part of the M_1 subinterval. There are other instances of "tight zones" which may or may not be due to silicification. Whether these would provide stratigraphic traps depends upon the time of silicification and time of oil migration, but the porosity differences necessary for such traps appear to be there.

M_2 subinterval:

The M_2 subinterval is about 125 to 150 feet thick. Log characteristics indicate a relatively "clean" carbonate unit. Samples of this subinterval are usually described as fine grained, fragmental, fossiliferous limestone, sometimes oolitic or pelletoidal and sometimes dolomitic, but never siliceous. This subinterval provides the reservoir rock for most of the Madison structural accumulations along the Nesson anticline. In some areas, such as Burke County, parts of this subinterval become anhydritic. Where this occurs, it provides stratigraphic traps. Many of the oil fields of Burke County possess this type of trap; similar stratigraphic trap accumulations may be present in this subinterval in the area of this study.

CONCLUSIONS

A large number of wells have penetrated Madison rocks in north-central North Dakota. Early exploration in this area was based largely on seismic work looking for structural traps or subcrops of Madison porosity zones at the pre-Spearfish unconformity. The relatively high drilling density based on the seismic prospects provided stratigraphic information necessary to recognize the presence of facies changes within the middle and upper Madison. Studies of these facies changes led to the discovery of favorable reservoir areas based on porosity differences due to these facies changes.

Study of log characteristics and samples of the lower Madison, as well as the lower part of the middle Madison, show that facies changes present in these parts of the Madison may also provide stratigraphic traps. In the area of study, the most notable of these facies changes is in the L_2 subinterval, but others may be found as more information becomes available. While present information may not be sufficient to start a "lower Madison play," deeper horizon prospecting should at least "take a look" at lower Madison possibilities.

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