Oil and Gas Potential of the Icebox Formation (Ordovician)

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TABLE OF CONTENTS

Illustrations ........................................................................................................................ iii
Tables ...................................................................................................................................... iv
Acknowledgments ................................................................................................................ iv
Abstract ............................................................................................................................... 1
Introduction .......................................................................................................................... 2
Previous Works .................................................................................................................... 2
Methods ............................................................................................................................... 4
Results .................................................................................................................................. 4
  Cross-sections .................................................................................................................. 12
  Cores .................................................................................................................................. 12
Discussion .......................................................................................................................... 31
  Depositional Environments and History ......................................................................... 31
  Major Sand Bodies ......................................................................................................... 32
  Other Sand Bodies ......................................................................................................... 34
Oil and Gas Potential ......................................................................................................... 35
  Production History ......................................................................................................... 35
  Tests .................................................................................................................................. 35
  Potential .......................................................................................................................... 45
Summary ............................................................................................................................ 46
References Cited ................................................................................................................ 49
ILLUSTRATIONS

Figure
Figure 1. Stratigraphic nomenclature of the Winnipeg Group ........................................... 2
Figure 2. Isopach map of the Icebox Formation .................................................................. 3
Figure 3. Study area ........................................................................................................... 4
Figure 4. Example of elimination of “off-scale effect” and digital conversion of
trace. Left—original gamma-ray log trace; right—gamma-ray log
trace overlain by spliced trace ....................................................................................... 5
Figure 5. Locations of wells used in this study ................................................................. 6
Figure 6. Distribution and thickness of sandy unit S1 ........................................................ 7
Figure 7. Distribution and thickness of sandy unit S2 ........................................................ 8
Figure 8. Distribution and thickness of sandy unit S3 ........................................................ 9
Figure 9. Distribution and thickness of sandy unit S5 ........................................................ 10
Figure 10. Distribution and thickness of sandy unit S6 ....................................................... 11
Figure 11. Distribution and thickness of sandy units S4 and S8 ........................................ 13
Figure 12. Distribution and thickness of sandy unit S10 .................................................... 14
Figure 13. Distribution and thickness of sandy unit S19 .................................................... 15
Figure 14. Distribution and thickness of sandy unit S32 .................................................... 16
Figure 15. Distribution and thickness of sandy units S7 and S9 ........................................ 17
Figure 16. Distribution and thickness of sandy units S11 and S14 ...................................... 18
Figure 17. Distribution and thickness of sandy units S15 ................................................... 19
Figure 18. Distribution and thickness of sandy unit S16 .................................................... 20
Figure 19. Distribution and thickness of sandy unit S17 .................................................... 21
Figure 20. Distribution and thickness of sandy unit S18 .................................................... 22
Figure 21. Distribution and thickness of sandy units S20, S22, and S29 ......................... 23
Figure 22. Distribution and thickness of sandy units S21 and S23 ..................................... 24
Figure 23. Distribution and thickness of sandy units S30 and S35 .................................... 25
Figure 24. Distribution and thickness of sandy units S36 .................................................. 26
Figure 25. Approximate stratigraphic positions of the major and extensive sand
bodies within the Icebox Formation .............................................................................. 28
Figure 26. Locations of cores which penetrated sandy bodies within the Icebox
Formation ...................................................................................................................... 29
Figure 27. Core of a sandy interval from the Icebox Formation, Divide County,
North Dakota .............................................................................................................. 30
Figure 28. Generalized paleoenvironmental interpretation for the major sand bodies
in the Icebox Formation .............................................................................................. 33
Figure 29. Sea level changes for part of the Ordovician in Iowa (after Witzke and
Bunker, 1996). Age assignments for the Winnipeg Group after
Thompson (1984) ......................................................................................................... 34
Figure 30. Locations of wells which have produced from the Winnipeg Group .............. 36
Figure 31. Locations of wells in which the Winnipeg Group was tested ......................... 38
Figure 32. Location of wells reporting gas in Winnipeg tests ........................................... 39
Figure 33. Location of wells reporting oil in Winnipeg tests .......................................... 40
Figure 34. Location of wells in which the Icebox Formation was tested ....................... 41
Figure 35. Locations and gamma-ray curves for the Sun Tronson and the Enserch Aasheim-Clark wells, Sheridan County, Montana. Dashed lines represent the center of the sand bodies. Heavy bars are the tested intervals.................................................................................................... 42

Figure 36. Gamma-ray curve and cored interval for the Amerada-Hess Federal well Sheridan County, Montana ............................................................. 44

Figure 37. Portion of the study area below the –5,000 ft structure contour on the top of the Icebox Formation................................................................. 47

Plates
Plate 1. West-East Cross Sections ................................................................. (on CD)
Plate 2. North-South Cross-Sections............................................................. (on CD)

TABLES

Table 1. Characteristics of the sand bodies in the Icebox Formation .................. 27
Table 2. Winnipeg Group producing wells......................................................... 37
Table 3. Production tests on the Icebox Formation ........................................... 43

ACKNOWLEDGMENTS

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ABSTRACT

The Icebox Fm (Ordovician) is a regionally extensive shale, the middle of three formations within the Winnipeg Group. Wireline gamma-ray logs were used to recognize and trace coarser lithofacies within the Icebox Formation in North Dakota and eastern Montana.

Forty distinct sandy lithofacies were identified in the study area. Five have regional extent, and cover most of the study area. Five additional sand bodies each extend across several 10s of miles. The remaining 30 identifiable bodies are of only local extent, and typically are evident in only a few wells. Based on the existing cores, it appears that the sandy lithofacies probably represent intervals of bioturbated sandstone and siltstone within the shalier Icebox Formation.

The bioturbated sandy intervals were probably deposited in a lower shoreface or shallow offshore environment. Areas of greater sand body thickness to the west probably represent deposition in shoreline settings. There were several shallowing episodes in the region during Icebox time.

The Winnipeg Group has produced from 14 wells in seven fields in North Dakota. All of the production is from the Black Island Formation, below the Icebox. The wells are primarily gas producers. No wells have produced from the Winnipeg in Montana.

Formation tests on the Winnipeg have been reported on 85 wells in North Dakota and eastern Montana. Nine tests were done on the Icebox Formation. Of the nine, four reported gas and three reported oil. Five of the nine, all in eastern Montana, appear to have tested the sand bodies in the Icebox.

On balance, it seems likely that the Icebox Formation, particularly the sand bodies, has some oil and gas potential. The sand bodies have only been tested in five locations in eastern Montana. Large areas of sand body occurrence are entirely untested. The sand bodies have the potential to be good reservoir rock, and their proximity to an extensive source rock would have facilitated the accumulation of hydrocarbons. Any production from the Icebox will probably be predominantly gas.
Introduction

The Icebox Formation (Ordovician) is the middle of three formations within the Winnipeg Group, underlain by the sandstones and siltstones of the Black Island Formation, and grading up into the argillaceous carbonates of the Roughlock Formation. (Fig. 1). It is a regionally extensive shale, typically dark green to black, and reaches a maximum thickness of about 190 ft (58 m) in the center of the basin. (Fig. 2).

Figure 1. Stratigraphic nomenclature of the Winnipeg Group

Previous Works

The Icebox Formation and the Winnipeg Group have been the subject of numerous studies over the past several decades (e.g., Andrichuk, 1959; Porter and Fuller, 1959; Carlson, 1960; 1964; Fuller, 1961; Paterson, 1971; Vigrass, 1971; McCabe, 1978; Carlson and Thompson, 1987; LeFever et al., 1987; Kessler, 1991; Ellingson and LeFever, 1995).

Descriptions of sandy intervals within the Icebox Fm have appeared in the literature for more than 30 years. Most notable is the “Carman sand” in Manitoba (Vigrass, 1971), but other localized accumulations in the Dakotas, Montana, Manitoba, and Saskatchewan have been described by various workers (e.g., Carlson, 1960; Carlson and Thompson, 1987; Kessler, 1991).
Figure 2. Isopach map of the Icebox Formation.
Methods

Wireline gamma-ray logs of the Icebox Formation from North Dakota and eastern Montana were examined. The area of study included all of North Dakota, and Montana from the eastern boundary west to about longitude 106W (Fig.3). One of the difficulties in working with gamma-ray traces of the Icebox Formation is that part of the trace is commonly off-scale; this characteristic makes it difficult to recognize units within the formation. To eliminate this “off-scale effect”, the traces were digitally reproduced and spliced into one continuous track (Fig. 4). The complete traces were then digitized and converted to LAS format. Some wells which penetrated the Icebox had no gamma-ray, and others had gamma-ray traces which were incomplete and could not be converted to digital form. Altogether, 365 well logs were converted (Fig. 5).

Figure 3. Study Area

Results

A total of 40 sandy lithofacies were identified in the study area; they were arbitrarily designated S1 - S40. Five have regional extent, and cover most of the study area (Figs. 6-10).
Figure 4. Example of elimination of “off-scale effect” and digital conversion of trace. Left - original gamma-ray log trace; right - gamma-ray log trace overlain by spliced trace.
Figure 5. Locations of the wells used in this study.
Figure 6. Distribution and thickness of sandy unit S1.
Figure 7. Distribution and thickness of sandy unit S2.
Figure 8. Distribution and thickness of sandy unit S2.
Figure 9. Distribution and thickness of sandy unit S5.
Figure 10. Distribution and thickness of sandy unit S6.
These major bodies have a maximum thickness of at least 20 ft (6 m), and one is 72 ft (22 m) at its thickest. Although typically 5-10 ft thick over much of North Dakota, the major bodies, with one exception, tend to thicken westward, and their greatest known thicknesses occur near their westward limits.

Five additional sand bodies each extend across several 10s of miles, and have maximum thicknesses ranging from 10 ft (3 m) to 23 ft (7 m) (Figs. 11-14). These extensive sand bodies average somewhat thinner than the major bodies, but show no obvious thickness trends.

The remaining 30 identifiable bodies are of only local extent, and typically are evident in only a few wells (Fig. 15-24). Table 1 summarizes the location data for the recognized sand bodies.

The sandy units appear to be distributed evenly throughout the Icebox Formation. The stratigraphic distribution of the major units is illustrated in Figure 25.

**Cross-sections**

Seven cross-sections were constructed, three east-west, and four north-south (Plates 1 & 2).

**Cores**

Only six cores have sampled the sandy bodies in the Icebox Formation in North Dakota (Fig. 26), all in the lower part of the formation. The core depicted in Figure 27, from the Icebox Fm in Divide County, includes sand body 3 (S3), and is typical of the cored bodies. Based on the existing cores, it appears that the sandy lithofacies probably represent intervals of bioturbated sandstone and siltstone within the shalier Icebox Formation.
Figure 11. Distribution and thickness of sandy units S4 and S8.
Figure 12. Distribution and thickness of sandy unit S10.
Figure 13. Distribution and thickness of sandy unit S19.
Figure 14. Distribution and thickness of sandy unit S32.
Figure 15. Distribution and thickness of sandy units S7 and S9.
Figure 16. Distribution and thickness of sandy units S11 and S14.
Figure 17. Distribution and thickness of sandy unit S15.
Figure 18. Distribution and thickness of sandy unit S16.
Figure 19. Distribution and thickness of sandy unit S17.
Figure 20. Distribution and thickness of sandy unit S18.
Figure 21. Distribution and thickness of sandy units S20, S22, and S29.
Figure 22. Distribution and thickness of sandy units S21 and S23.
Figure 23. Distribution and thickness of sandy units S30 and S35.
Figure 24. Distribution and thickness of sandy unit S36.
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<th>Max.</th>
<th>Location</th>
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<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
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<td>23 ft</td>
<td>Entire study area</td>
</tr>
<tr>
<td>S2</td>
<td>128</td>
<td>72 ft</td>
<td>Western part of the study area</td>
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<tr>
<td>S3</td>
<td>247</td>
<td>23 ft</td>
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<tr>
<td>S5</td>
<td>160</td>
<td>34 ft</td>
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<tr>
<td>S6</td>
<td>108</td>
<td>21 ft</td>
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<td>Northwestern part of study area</td>
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<td>S8</td>
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<td>East-central North Dakota</td>
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<tr>
<td>S10</td>
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<tr>
<td>S19</td>
<td>17</td>
<td>18 ft</td>
<td>East-central North Dakota</td>
</tr>
<tr>
<td>S32</td>
<td>25</td>
<td>20 ft</td>
<td>Nesson Anticline in North Dakota</td>
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<td>Southeastern North Dakota</td>
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<td>7</td>
<td>21 ft</td>
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<td>S16</td>
<td>4</td>
<td>10 ft</td>
<td>East-central North Dakota</td>
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<td>S18</td>
<td>4</td>
<td>23 ft</td>
<td>East-central North Dakota</td>
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<td>Eastern Montana</td>
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<tr>
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<td>9 ft</td>
<td>Emmons County, North Dakota</td>
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<tr>
<td>S13</td>
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<tr>
<td>S17</td>
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<td>Morton County, North Dakota</td>
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<td>S28</td>
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<td>Sheridan County, Montana</td>
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<td>S37</td>
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<td>Eastern Montana</td>
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<td>25 ft</td>
<td>McCon County, Montana</td>
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<tr>
<td>S40</td>
<td>1</td>
<td>10 ft</td>
<td>Fallon County, Montana</td>
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</table>
Figure 25. Approximate stratigraphic positions of the major and extensive sand bodies within the Icebox Formation.
Figure 26. Locations of cores which penetrated sandy bodies within the Icebox Formation.
Figure 27. Core of a sandy interval from the Icebox Formation, Divide County, North Dakota.
Discussion

Depositional Environments and History

The Icebox Formation consists predominantly of greenish-gray to dark greenish-gray shale. Bioturbation is common throughout the Icebox Formation; prominent burrows occur locally. Local zones within the Icebox shales are fossiliferous, and contain brachiopods, trilobite fragments, and numerous other unidentifiable fossil fragments.

The Icebox Formation was deposited in a marine environment, seaward of the nearshore environments (Thompson, 1984; Carlson and Thompson, 1984; LeFever et al., 1987; Ellingson and LeFever, 1995). Normal marine conditions are indicated by the invertebrates present; the high degree of bioturbation indicates that oxidizing conditions existed for at least the upper part of the substrate. The depth of water is uncertain, but the presence of several sandy lithosomes may indicate that depths were not great. The lack of coarse material may reflect distance from shore rather than water depth.

The Winnipeg Group represents the initial deposits of the mid-Ordovician transgression (basal Tippecanoe sequence). The Black Island Formation was deposited under fluvial/deltaic, and, later, shallow marine and shoreline conditions. Sea level continued to rise throughout Black Island time. By the end of Black Island time, the sea covered all of the basin, and shales of the Icebox Formation were being deposited throughout most of the central basin.

Further sea level rise and migration of the shoreline gradually covered the sources of the fine-grained sediment of the Icebox Formation. The reduction in argillaceous input allowed carbonate sediment production to begin farther offshore, and the argillaceous carbonates of the Roughlock Formation were deposited. Over time, the sources of clastic sediment were completely covered, and the Roughlock Formation was succeeded by the cleaner carbonates of
the Red River Formation.

**Major Sand Bodies**

The bioturbated sandy intervals which have been cored in the Icebox Formation strongly resemble the bioturbated portions of the upper part of the Black Island Formation, and were probably deposited under similar conditions, in a lower shoreface or shallow offshore environment (Thompson, 1984; LeFever et al., 1987; Ellingson and LeFever, 1995). The thinner portions of the major sand bodies over most of the study area exhibit log characteristics similar to the cored intervals, and probably represent similar environments.

Areas of greater sand body thickness to the west probably represent deposition in shoreline settings. That interpretation is based on two lines of reasoning: 1) thickening to the west is consistent with deposition closer to the source (shallower water); and 2) some (although not all) of the gamma ray log traces of the thicker sand bodies show a coarsening-upward log character, which is consistent with shoreline deposition. It should be noted that no core data exist to support this interpretation. The interpretation of the paleoenvironments in the area over Icebox time is depicted in Figure 28.

The occurrence of regionally extensive sand bodies within the shales of the Icebox Formation indicates that there were several shallowing episodes in the region during Icebox time. Although the Icebox was deposited during a long-term sea level rise, over the short term sea levels in the region must have fluctuated. Something similar was described for the Ordovician of Iowa, where several short-term fluctuations were superimposed on the overall sea level rise (Fig. 29; Witzke and Bunker, 1996). Whether the fluctuations in sea level recorded in North Dakota and Montana were eustatic or the result of local conditions has yet to be determined.
Figure 28. Generalized paleoenvironmental interpretation for the major sand bodies in the Icebox Formation.
Other Sand Bodies

The other sand bodies, whether classified as extensive, minor or isolated, do not appear to have resulted from significant basinwide sea level fluctuations. Because of their limited geographic extent, it seems likely that many were deposited on top of smaller topographic highs, perhaps associated with local structural features. In such cases, a small sea level drop might have been enough to allow some sediment to accumulate on top of such features, without

Figure 29. Sea level changes for part of the Ordovician in Iowa (after Witzke and Bunker, 1996). Age assignments for the Winnipeg Group after Thompson (1984).
producing regionally extensive coarser lithofacies. Examples of sandy bodies associated with known local features include: S32 (Nesson Anticline), S11 (Burleigh-Emmons County high), S15, S16, S17 and S18 (Stutsman County high).

Oil and Gas Potential

Production History

The Winnipeg Group has produced from 14 wells in seven fields in North Dakota (Fig. 30; Table 2). Not all of the wells are still active producers. All of the production is from the Black Island Formation, below the Icebox. Although there is minor oil production, the wells are primarily gas producers. There appears to have been no Winnipeg production in Montana.

Tests

Formation tests on the Winnipeg Group, including both drill stem tests and production tests, have been reported on 85 wells in North Dakota and eastern Montana (Fig. 31). Of the 85 tests, 43 reported gas from the Winnipeg (Fig. 32), and 9 reported oil (Fig. 33).

Most of the reported tests were done on the Black Island Formation, or on an interval which included the Black Island and some of the overlying Icebox, or some of the underlying Deadwood Formation. Nine tests were done on the Icebox Formation (Fig. 34). Of the nine, four reported gas and three reported oil. Five of the nine, all in eastern Montana, appear to have tested the sand bodies in the Icebox; one test reported oil, one gas, and one both.

Production tests were run on the Icebox in two wells in Sheridan County, Montana (Fig. 35; Table 3). In both cases, the tested interval was in a thick section of one of the sandy units.

We have obtained one analysis from core of the Icebox Formation, which was taken in eastern Montana, at the Amerada-Hess Federal #36-44 (SESE Sec. 36, T32N R54E, Sheridan County; Fig. 36). The core was taken in the lower Icebox and includes all of sand body S2 and a small part of sand S3. The analysis describes the S2 sand as fine to very fine-grained, locally
Figure 30. Locations of wells which have produced from the Winnipeg Group.
<table>
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<tr>
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</table>

*Abandoned
Figure 31. Locations of wells in which the Winnipeg Group was tested.
Figure 32. Locations of wells reporting gas in Winnipeg.
Figure 33. Locations of wells reporting oil in Winnipeg tests.
Figure 34. Locations of wells in which the Icebox Formation was tested.
Figure 35. Locations and gamma-ray curves for the Sun Tronson and the Enserch Aasheim-Clark wells, Sheridan County, Montana. Dashed lines represent the centers of the sand bodies. Heavy bars are the tested intervals.
<table>
<thead>
<tr>
<th>Date</th>
<th>Well</th>
<th>Location</th>
<th>DST</th>
<th>Production test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>Sun Oil Co. #1 Tronson</td>
<td>NENW Sec. 27, T32N R56E</td>
<td>SC: 12 cf gas, 400 cc oil</td>
<td>2 bbl oil 150 MCF gas</td>
</tr>
<tr>
<td>1983</td>
<td>Enserch Exploration, Inc. #1-13 Aasheim-Clark</td>
<td>NWNW Sec. 13, T34N R55E</td>
<td>None</td>
<td>2400 gal oil</td>
</tr>
</tbody>
</table>
Figure 36. Gamma-ray curve and cored interval for the Amerada-Hess #36-44 Federal well Sheridan County, Montana.
shaly, with some pyrite. Reported permeabilities averaged about 21 md (.01 - 90 md), and porosity averaged 7.3% (2.5 - 12.1%). Oil saturation ranged from 0 to 28.7% (average 7.3%), and water saturation from 4.7% to 43.7% (average 20.4%).

Potential

The only previous work on the production history and potential of the Winnipeg over the Williston Basin in North Dakota and Montana is Anderson’s (1982) thorough summary. His study was concerned entirely with the history and potential of the Winnipeg Sand (Black Island Formation), and did not address the Icebox Formation at all.

The oil and gas potential of the Icebox Formation within the area studied is difficult to assess for two reasons. First, there are comparatively few wells which encounter it in the area; only about 400 out of the more than 22,000 wells in North Dakota and eastern Montana are deep enough to penetrate the Icebox. Second, tests reported on the Winnipeg Group include only 85 wells, only about 20% of the wells drilled to that level. Of the 85, only nine appear to have tested the Icebox Formation.

Despite the relative lack of data on the Icebox Formation within the area, there are some grounds to consider it to have potential as a hydrocarbon producer. First, although only five wells have tested the sand bodies in the Icebox, three of the five reported hydrocarbons, two in significant quantities.

Second, based on the tests run and on the log characteristics, the sand bodies are good candidates for reservoir rock, and their interbedding with an extensive source rock would have made it comparatively easy for hydrocarbons generated in the source rock to have accumulated in the sand bodies. The Icebox is considered to be a source rock for the Lower Paleozoic in the Williston Basin (Dow, 1974; Osadetz et al., 1994; Burrus et al., 1995). Dow (1974) considered
that the maximum extent of effective Winnipeg source rocks in the Williston Basin, as
determined from studies of thermal alteration of organic matter, is defined by the -5,000 ft
contour on the top of the Icebox shales on the east, and on the west by the depositional limit of
the shale. Using those criteria, a large fraction of the study area would be considered thermally
mature enough to generate hydrocarbons from the Icebox (Fig. 37).

On balance, it seems likely that the Icebox Formation, particularly the sand bodies, has
some oil and gas potential. The sand bodies have only been tested in five locations in eastern
Montana. Large areas of sand body occurrence are entirely untested. The major sand bodies
cover very large areas, and reach thicknesses of tens of feet in the counties along the North
Dakota-Montana border. Several of the bodies classified above as extensive or minor reach
thicknesses of more than 10 feet, and, collectively, cover a large portion of the area.

Based on the Icebox tests and the Winnipeg production from the fields in North Dakota,
it seems likely that any production from the Icebox will be predominantly gas, although some
oil seems to be present.

Summary

The Icebox Formation (Ordovician) is a regionally extensive shale, the middle of three
formations within the Winnipeg Group. Wireline gamma-ray logs were used to study the
Icebox Formation in North Dakota and eastern Montana. The gamma-ray traces were
converted to digital format to allow us to recognize and trace coarser lithofacies within the
shale.

Forty sandy lithofacies were identified in the study area. Five have regional extent, and
cover most of the study area. These major bodies tend to thicken westward, and their maximum
thicknesses occur near their westward limits. Five additional sand bodies each extend across
Figure 37. Portion of the study area below the -5,000 ft structure contour on the top of the Icebox Formation.
distance from shore rather than water depth.

The bioturbated sandy intervals were probably deposited in a lower shoreface or shallow offshore environment. Areas of greater sand body thickness to the west probably represent deposition in shoreline settings. There were several shallowing episodes in the region during Icebox time.

The less extensive sand bodies do not appear to have resulted from significant basinwide sea level fluctuations. It seems likely that many were deposited on top of smaller topographic highs, perhaps associated with local structural features.

The Winnipeg Group has produced from 14 wells in seven fields in North Dakota. All of the production is from the Black Island Formation, below the Icebox. The wells are primarily gas producers.

Formation tests on the Winnipeg Group, including both drill stem tests and production tests, have been reported on 85 wells in North Dakota and eastern Montana. Nine tests were done on the Icebox Formation. Of the nine, four reported gas and three reported oil. Five of the nine, all in eastern Montana, appear to have tested the sand bodies in the Icebox; one test reported oil, one gas, and one both.

On balance, it seems likely that the Icebox Formation, particularly the sand bodies, has some oil and gas potential. The sand bodies have only been tested in five locations in eastern Montana. Large areas of sand body occurrence are entirely untested. The sand bodies are good candidates for reservoir rock, and interbedding with an extensive source rock would have allowed generated hydrocarbons to accumulate in the sand bodies. Any production from the Icebox will probably be predominantly gas.
References Cited


