DEPARTMENT OF INTERIOR

U.S. GEOLOGICAL SURVEY

A statistical analysis of the larger Silurian reefs in the northern part of the Lower Peninsula of Michigan

by

Ronald R. Charpentier[1]

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[1] Denver, Colorado 80225

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ABSTRACT

The Silurian reef trend in the northern part of the Michigan basin includes 224 fields of at least one million barrels of oil equivalent in size. Analysis of data for these 224 fields gives information suitable for use as an analog in play-level appraisal of undiscovered hydrocarbon resources. Distributions of volumetric sizes of the reservoirs are very skewed, as are such reservoir characteristics as net pay thickness. Depth to the top of reservoir is the only parameter that shows a clear geographic distribution within the reef trend. Since 1974, there have been strong declines both in discovery rate and in the sizes of the fields found.

INTRODUCTION

In the recent appraisal of undiscovered resources of oil and natural gas by Mast and others (1988, also in U.S. Geological Survey and Minerals Management Service, 1988), fields equal to or larger than 1 million barrels of oil or six billion cubic feet of natural gas, recoverable, were assessed by a play analysis approach. A play, in this context, is a group of fields or prospects related by similar geologic characteristics. Play analysis uses probabilistic methods to estimate amounts of undiscovered resource based on probability distributions of field sizes or other geologic factors as well as on assessment of risk.

Such appraisals rely heavily on comparison of assessed areas to better-explored analogous areas. The present study has been performed to address the specific need of play-scale analogs for hydrocarbon appraisal of larger fields. It provides an example of what can be generated relatively simply from commercially-available data.

GENERAL GEOLOGIC SETTING

The northern Michigan Silurian reef play consists of oil and gas accumulations trapped in reefs of Niagaran (Middle Silurian) age. The reefs form a linear trend about 6 miles wide and 150 miles long in the northern part of the Lower Peninsula of Michigan (figure 1). This trend is part of a larger pinnacle reef trend which circles the deeper part of the basin. As of 1985, about 650 fields had been discovered in this trend. Of these, 224 are greater than or equal to one million barrels of oil equivalent (BOE) in size.

The Silurian reefs of the Michigan basin produce an oil distinct from those produced in the other fields in the

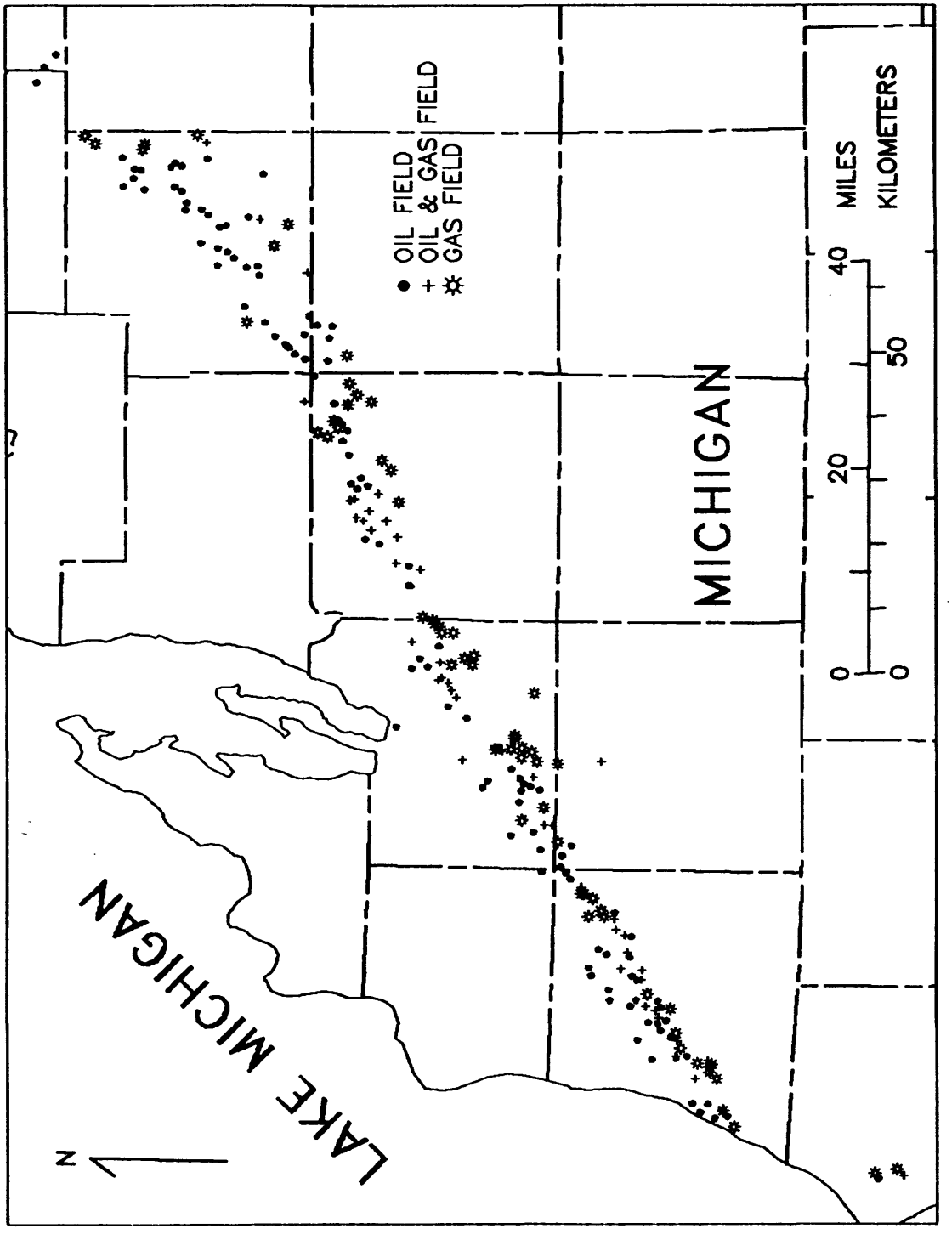


Figure 1. Location map of the northwestern part of the Lower Peninsula of Michigan showing fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

Michigan basin (Rullkotter and others, 1986). Gardner and Bray (1984) used carbon-isotope data to correlate oils with potential source rocks and concluded that the Silurian Salina A-1 carbonates were probably the principal source rocks, with some lesser contribution from part of the Niagaran reef carbonates themselves.

SOURCE OF DATA

All data used in this analysis came from the Significant Oil and Gas Fields of the United States Data Base, a product of NRG Associates, Inc. (1988). The version used included discoveries up to and including 1985. The production and reserve data used for the analysis were as of the end of 1985. Known recovery, as used in this paper, refers to the sum of cumulative production plus reserves, both as of 1985. The number of wells in each field was also taken as of 1985. Barrels of oil equivalent (BOE) were based on a conversion factor of 6000 cubic feet of gas per barrel of oil.

The NRG data base includes 343 fields from the Michigan basin. Included in the NRG files are those fields with at least 1 million BOE of known recovery and also those slightly smaller, but expected to eventually be revised to at least 1 million BOE. Of these 343 fields, 225 are classified as part of the northern Michigan Niagaran oil and gas productive trend (cluster 929, in the NRG terminology). Of these 225, one was smaller than 1 million BOE in size and was eliminated for consistency. The remaining 224 fields served as the base for the analysis.

DATA ANALYSIS

Play Definition

The fields within the northern Michigan Silurian reef play are all in stratigraphic traps associated with pinnacle reefs which are usually about 50 to 200 acres in area and 300 to 600 feet high. Production is primarily from the Niagaran reefs themselves (205 of 224 fields), but a few fields produce from the carbonates of the enclosing Salina Group (the remaining 19 of 224 fields). Almost all fields (220 of 224) produce from just a single reservoir, but three fields have two reservoirs each and one has three reservoirs.

Oil, mixed oil and gas, and gas fields are all found within the trend, but oil fields predominate (figure 2). The oil fields are mostly located on the northwest side of the trend and the gas and mixed oil and gas fields are on the southeast side (figure 1). This is the result of differential migration of the hydrocarbons (Gill, 1979). As the hydrocarbons migrated updip from the southeast, the first

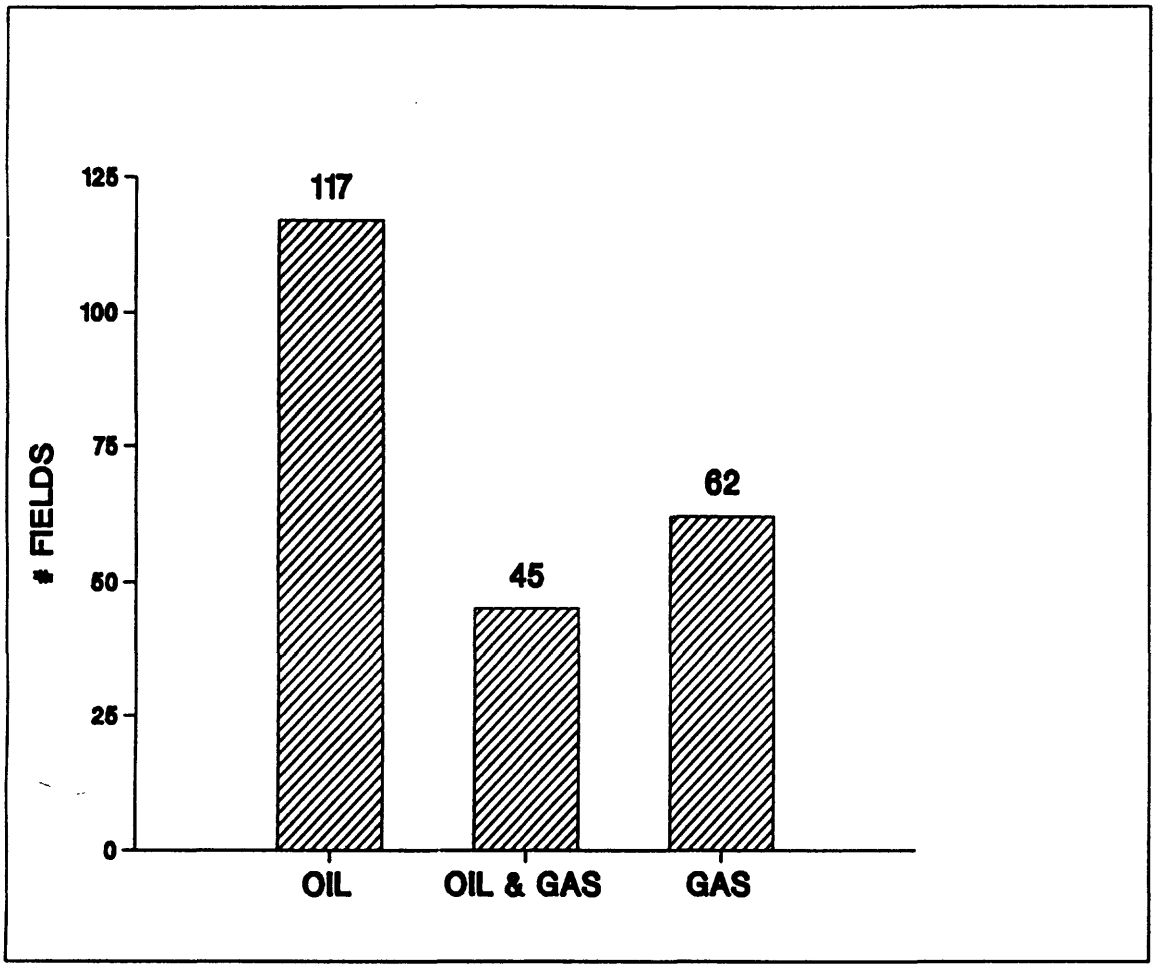


Figure 2. Bar chart comparing number of oil fields, mixed oil and gas fields, and gas fields for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

rank of reefs was filled. The reefs to the northwest were filled by the overflow from the first rank. Because gas is lighter than oil and the spillage was from the base of the traps, gas was preferentially left in the first rank of reefs while oil spilled into the further ranks.

Reservoir Characteristics

Figure 3 shows the distribution of depth to the top of the primary reservoir. In map view (figure 4), it can be seen that the depths are at about 3500 feet near the ends of the trend and about 7000 feet in the center. The depths reflect post-Niagaran tectonics and sedimentation within the Michigan basin. Supposedly, the reef trend would have paralled depth contours when originally formed. The distribution of depths is bimodal and somewhat negatively skewed. This results from the intersection of the trend with the dipping surface of the top of the reservoirs. The reef trend parallels the contours from 6000 to 7000 feet, and thus many reefs are at that depth. From 5000 to 5500 feet the contours are perpendicular to the trend, leading to few reefs at that depth. Shallower than 5000 feet the trend is still perpendicular to the contours but slopes are gentler, leaving room for more reefs at those depths. Separation of the fields into groups by hydrocarbon type (figure 5) shows that the basic form of the distribution is the same, but, as expected, the gas fields are somewhat deeper, being on the deeper, southeast side of the trend.

Dolomite is the reservoir lithology in 221 of 224 fields, but one field produces from limestone and two produce from limestone plus dolomite. Both intercrystalline and vugular porosity occur, with porosity averaging about eight percent.

The distribution of net pay thickness is very positively skewed (figure 6). Skewed distributions usually result when the variable measured is the product of more basic variables. Net pay thickness is the product of the more basic, yet unreported, variables of trap thickness and percent trap fill. Net pay thickness varies greatly from reef to reef with no apparent geographic trends.

Distributions of the API gravity of oils and of natural gas liquids are shown in figure 7. Both show fairly normal distributions. No geographic trends in API gravity are apparent for either. A plot of API gravity versus depth (figure 8) also shows no significant trends.

An average gas analysis is presented in table 1. No trends, either geographic or with depth, are evident.

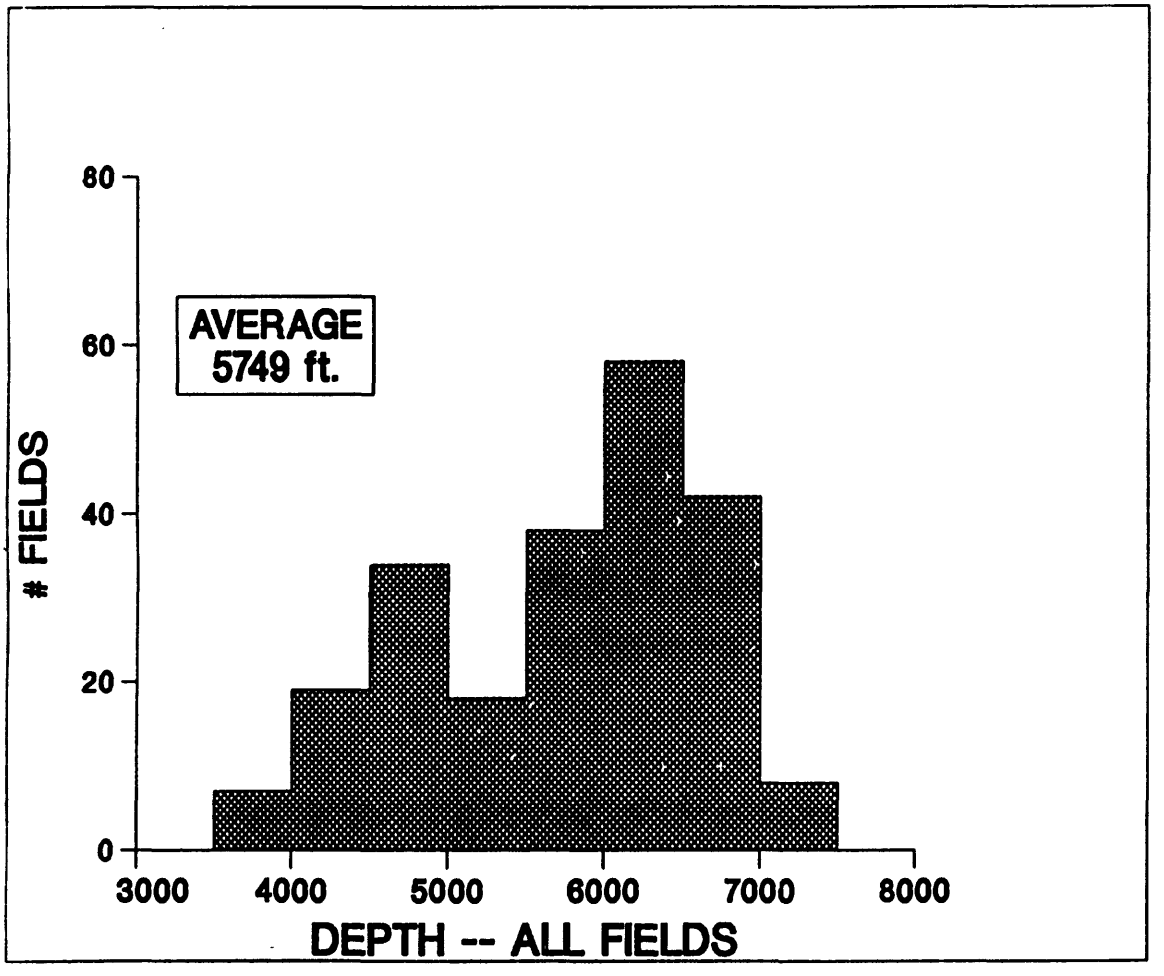


Figure 3. Histogram showing distribution of depth to top of the primary reservoir (in feet) for all 224 fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

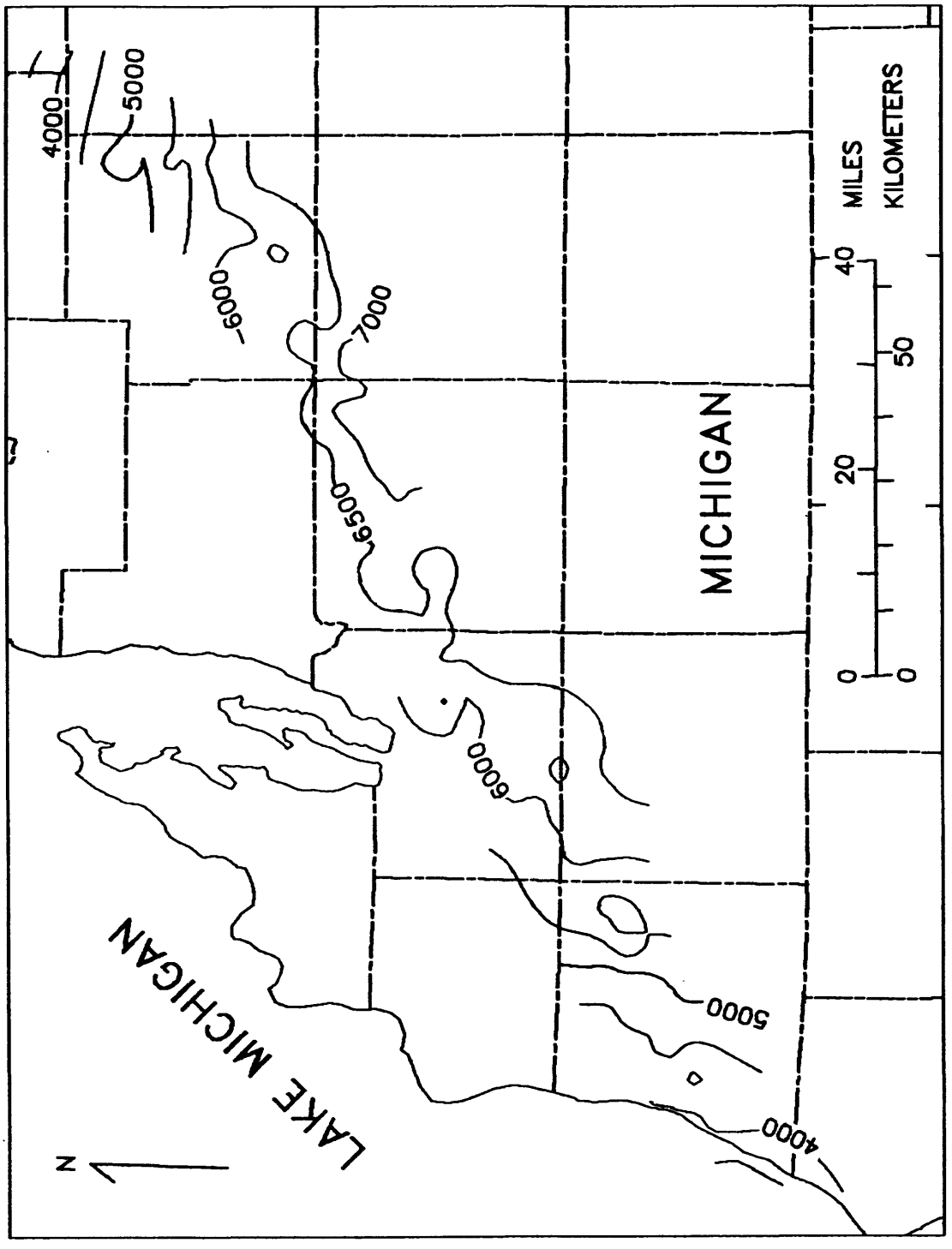


Figure 4. Map of the northwestern part of the Lower Peninsula of Michigan showing geographic distribution of depth to top of the primary reservoir (in feet) for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play. Contour interval 500 feet.

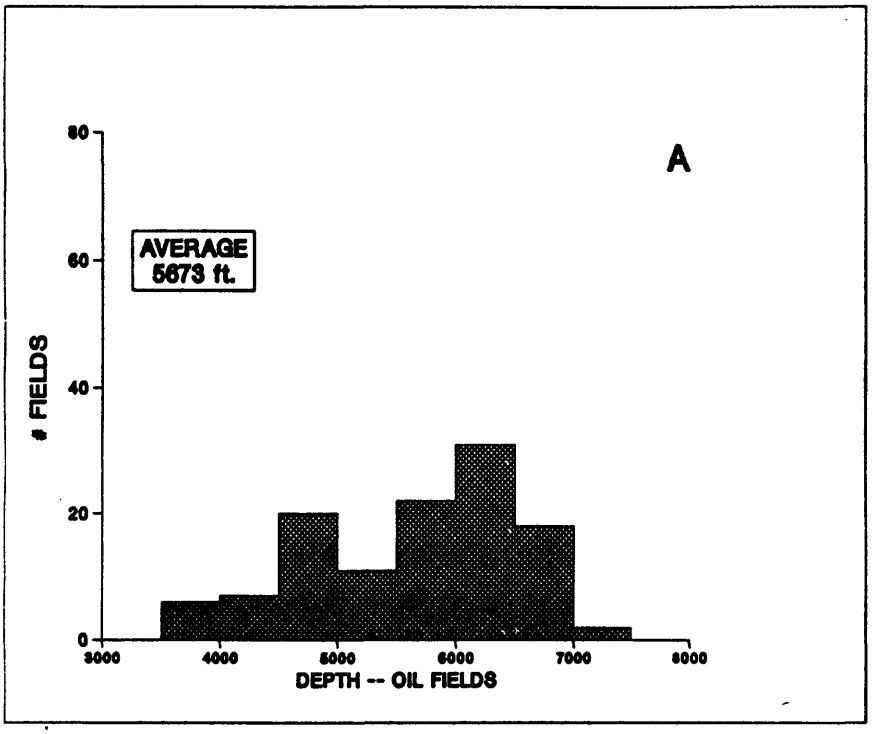
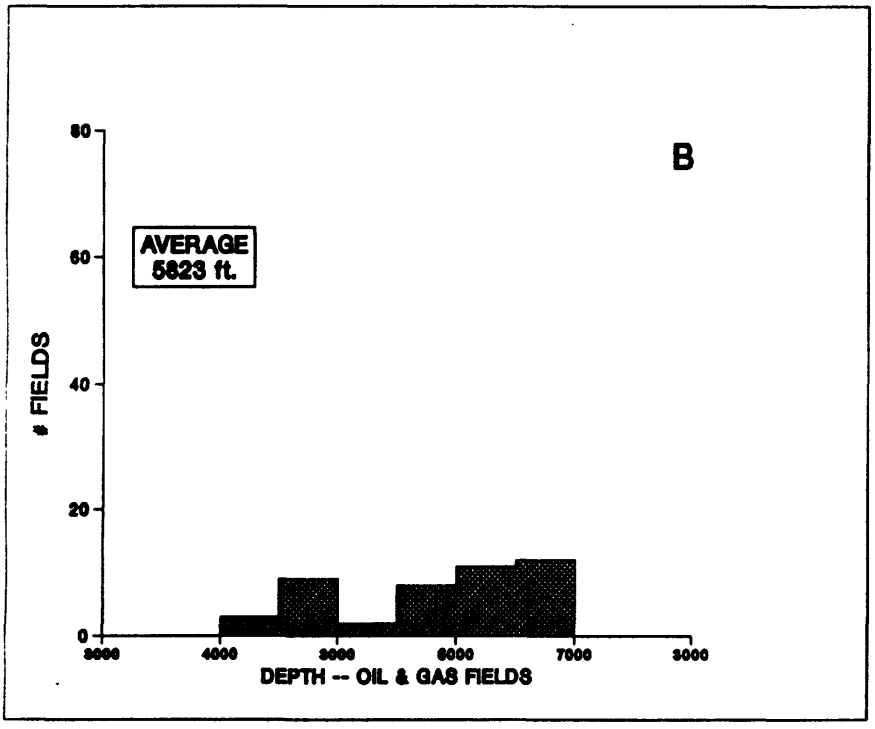


Figure 5. Histograms showing distribution of depth to the top of the primary reservoir (in feet) for: (A) oil fields, (B) oil and gas fields, and (C) gas fields for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.



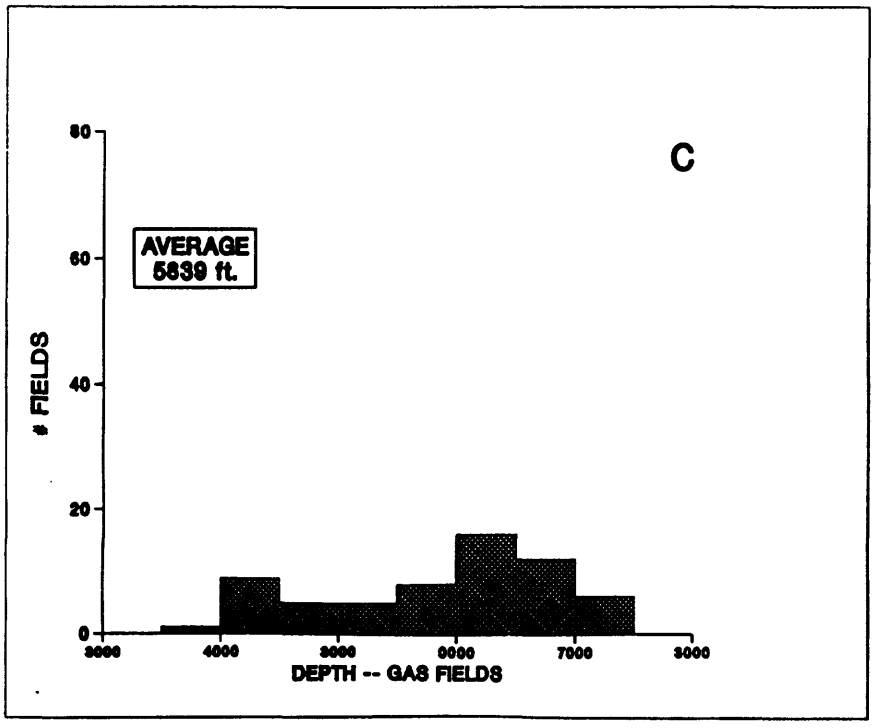


Figure 5. (continued)

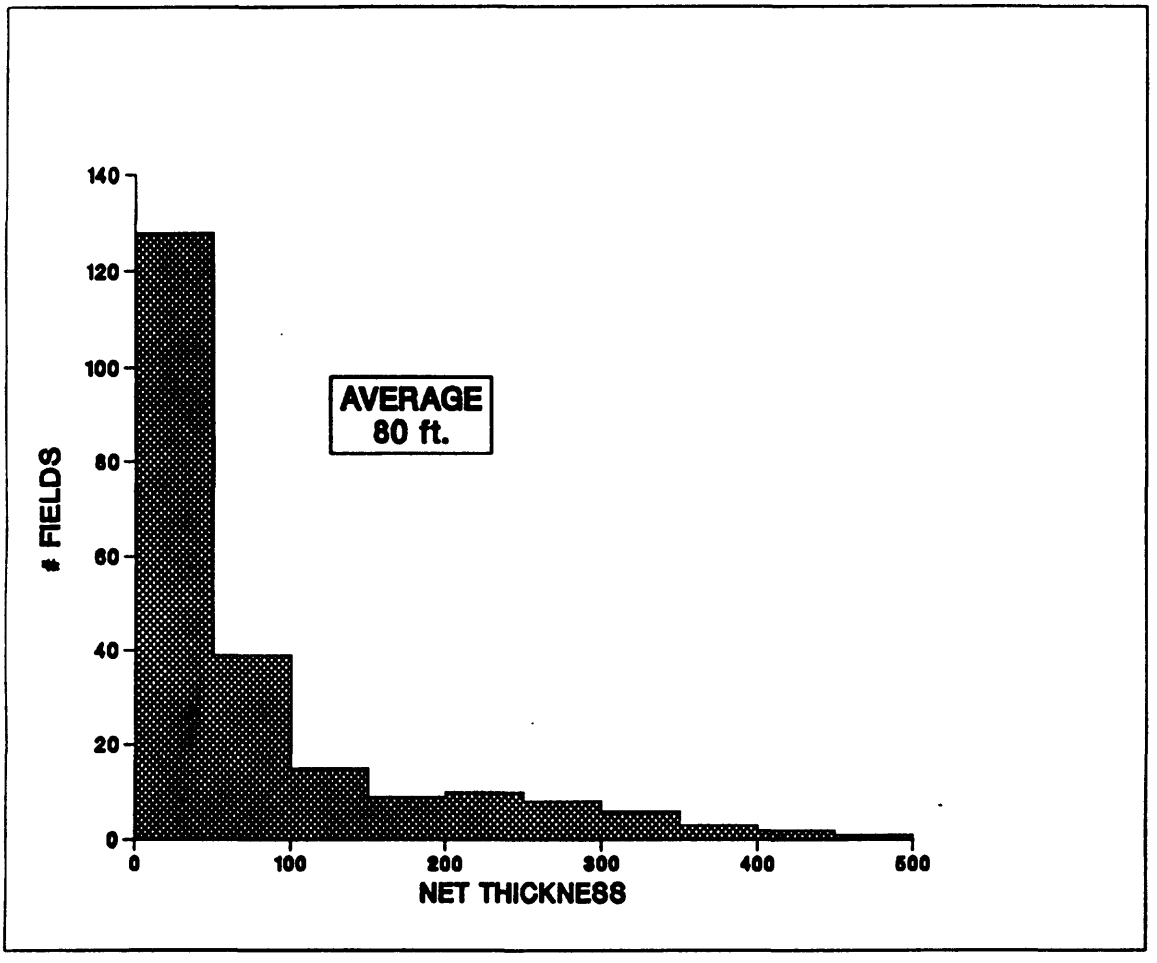


Figure 6. Histogram showing distribution of net pay thickness (in feet) for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

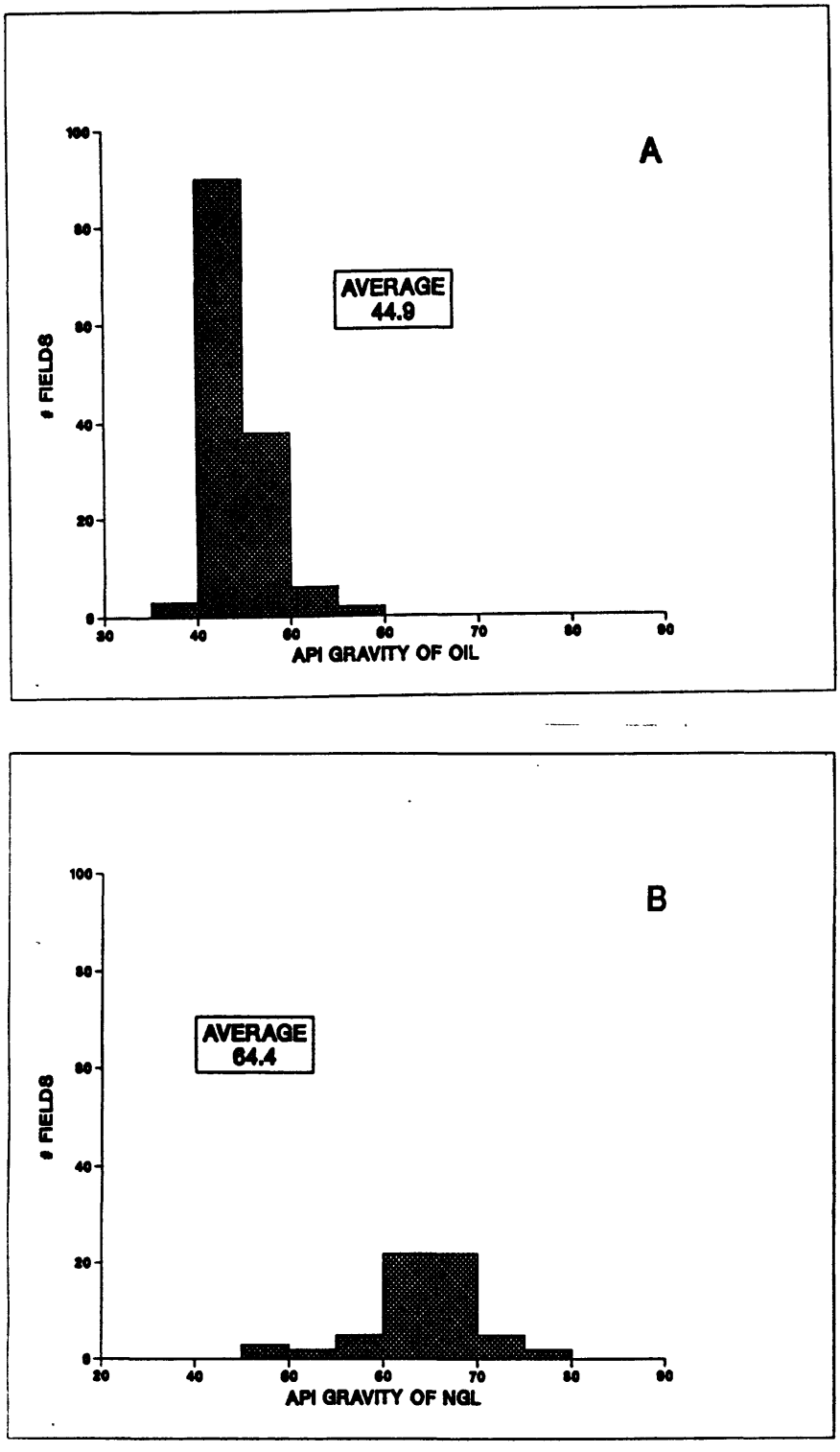


Figure 7. Histograms showing distributions of API gravity for: (A) oil, and (B) natural gas liquids for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

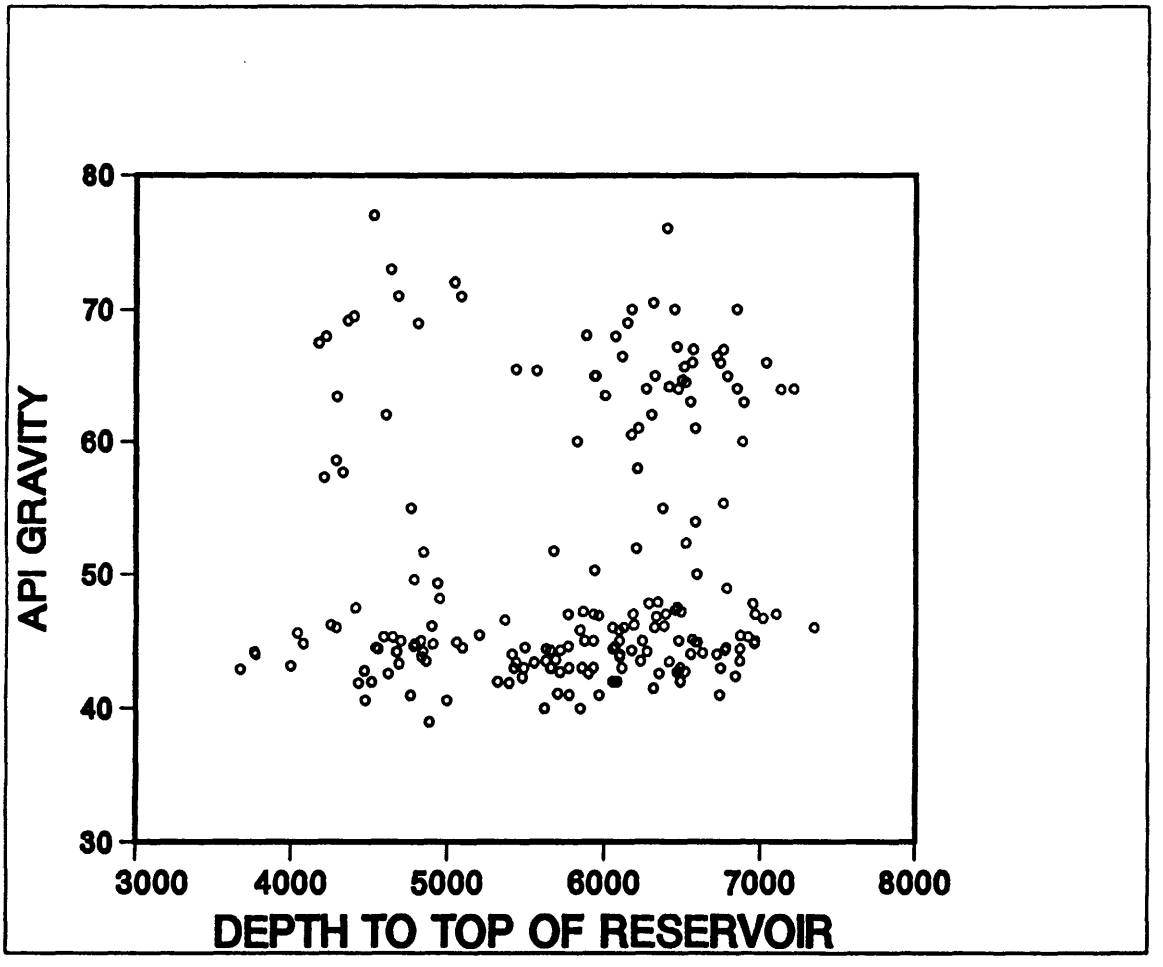


Figure 8. Plot of API gravity versus depth to top of reservoir (in feet) for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

Table 1

Average gas analysis

methane	82.3%	hexanes	0.2%
ethane	7.6%	carbon dioxide	0.3%
propane	3.5%	hydrogen sulfide	0.0%
butanes	2.5%	nitrogen	2.4%
pentanes	0.9%	helium	0.0%

Based on the average of analyses from eight fields. The NRG file reports gas compositiion by reservoir, which in itself could be an average of several analyses. Thus the actual number of gas analyses averaged for this table is unknown.

Discovery History

Except for one field found in 1951, at the same time as exploration of the southeast Michigan Silurian reef play, and one small (less than 1 million BOE) field found in 1959, discovery of the fields in the northern Michigan Silurian reef play began in 1969. The hiatus between the times of exploration in the two reef plays was due to the thick sequence of glacial drift, up to almost 1000 feet thick, in northern Michigan. Only with improved seismic interpretation in the late 1960's did it become practical to explore for pinnacle reefs in northern Michigan. All of the reefs found in this trend were located using seismic methods, although a combination of both seismic and subsurface geology is credited for the discovery of one of the fields.

Figure 9 shows the number of discoveries per year in the northern reef trend. After a rapid series of discoveries from 1969 to 1974, decline in the discovery rate has taken place as fewer untested prospects were available. The decline has not just been in number of discovered fields, but also in total resources discovered per year (figure 10). Figure 11, which shows size of discovered fields for each year, shows a strong declining trend with time in the largest fields found. No fields larger than 10 million BOE have been discovered since 1974.

Production

Even the larger fields within the northern Michigan Silurian reef trend are small by national standards. Only five fields are greater than 10 million BOE in size. The size distribution is very positively skewed (figure 12) and close to lognormal (figure 13). Viewed separately, oil and gas field size distributions are also very skewed (figures 14 to 17).

Producing acreages are small (figure 18) and average about 265 acres. It should be noted that the producing acreages reported are usually an even multiple of 80 acres and only approximate the actual reservoir or reef acreage. Few wells are thus needed to develop the fields, and most fields have fewer than five wells (figure 19).

Gas/oil ratios average about 1750 cubic feet per barrel for oil fields and 8790 cubic feet per barrel for mixed oil and gas fields. Their distribution is positively skewed (figure 20). Gas/oil ratios do not show a significant trend with depth (figure 21), but the figure does show that 4000 cubic feet per barrel gas/oil ratio is used as the dividing line between oil fields and mixed oil and gas fields.

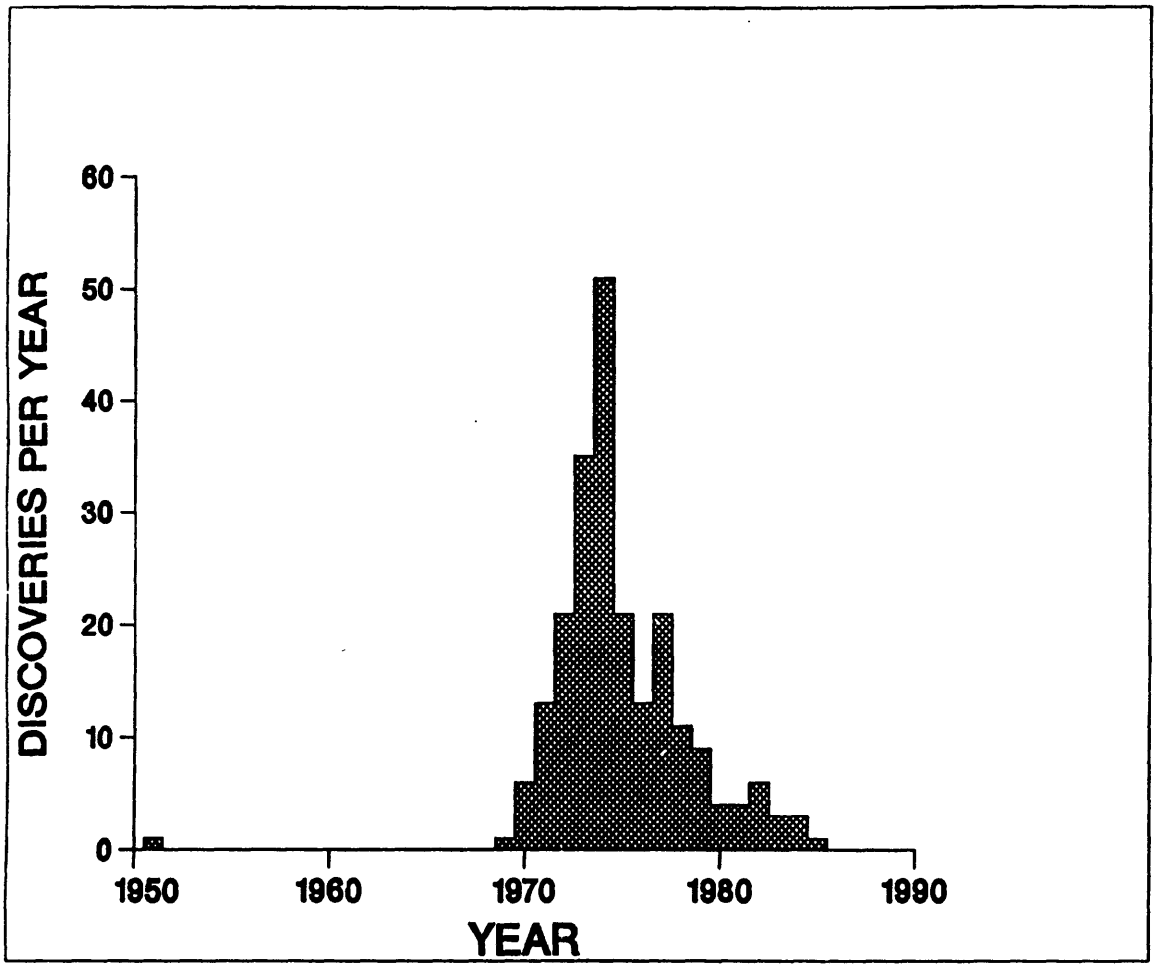


Figure 9. Histogram showing number of discoveries per year of fields with 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

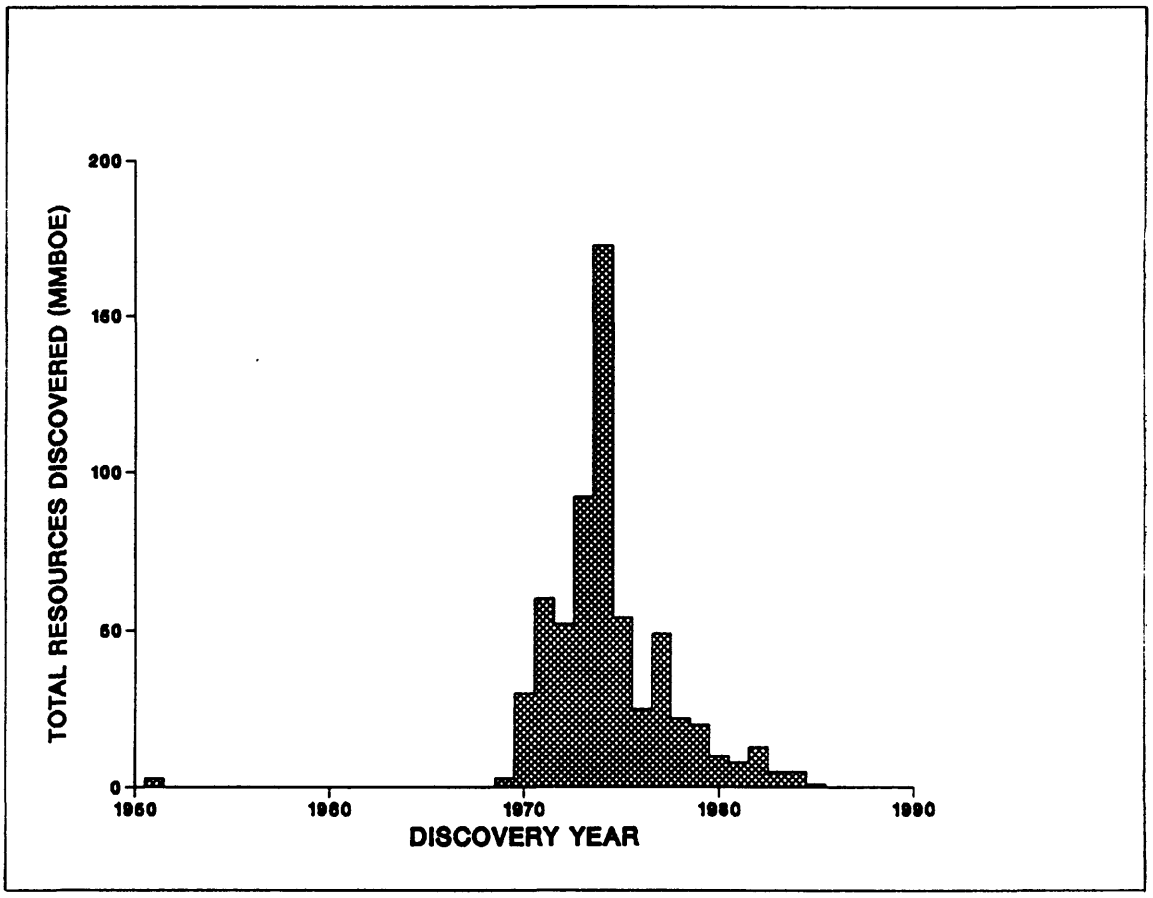


Figure 10. Histogram showing total amount of resource (in million BOE known recovery) discovered per year in fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

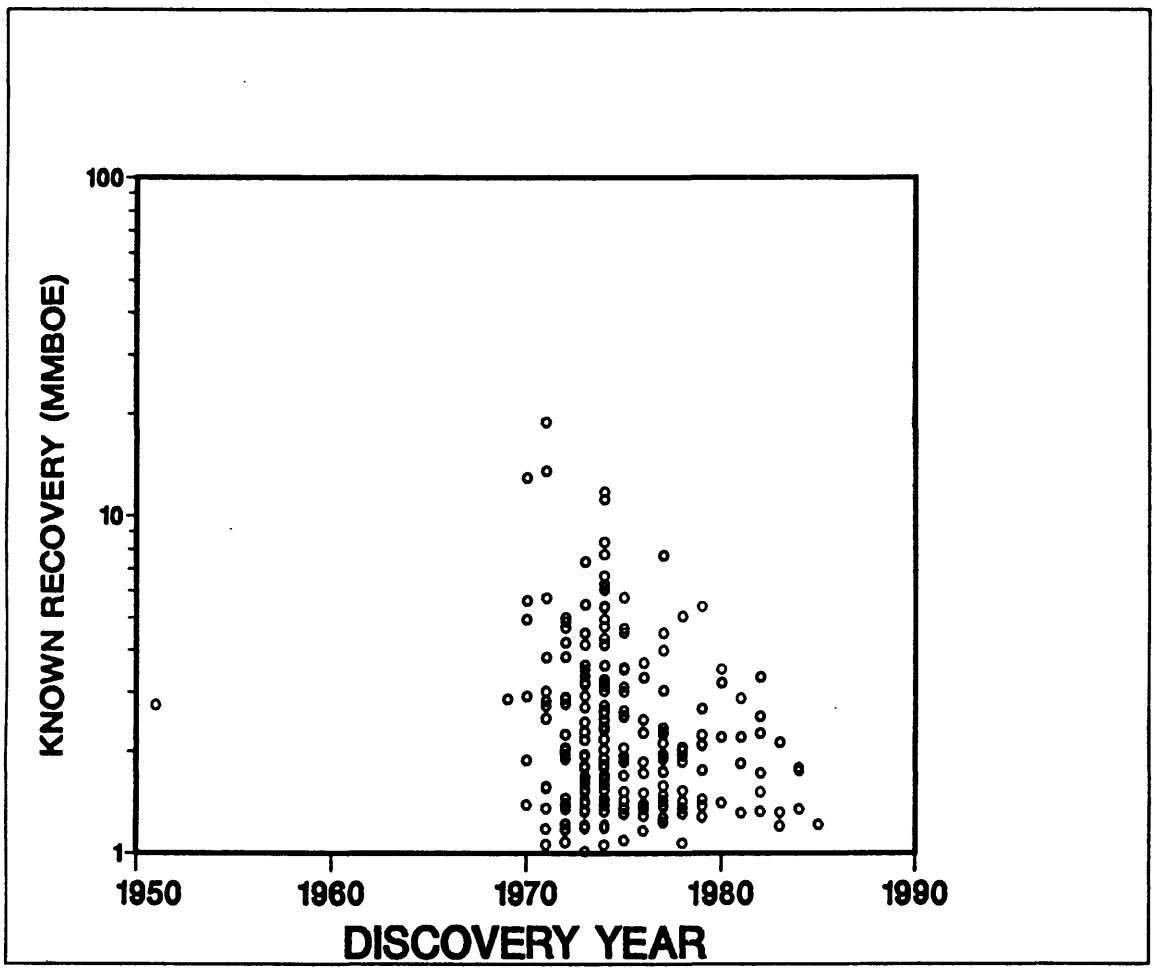


Figure 11. Plot of field size (in million BOE known recovery) versus discovery year of fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

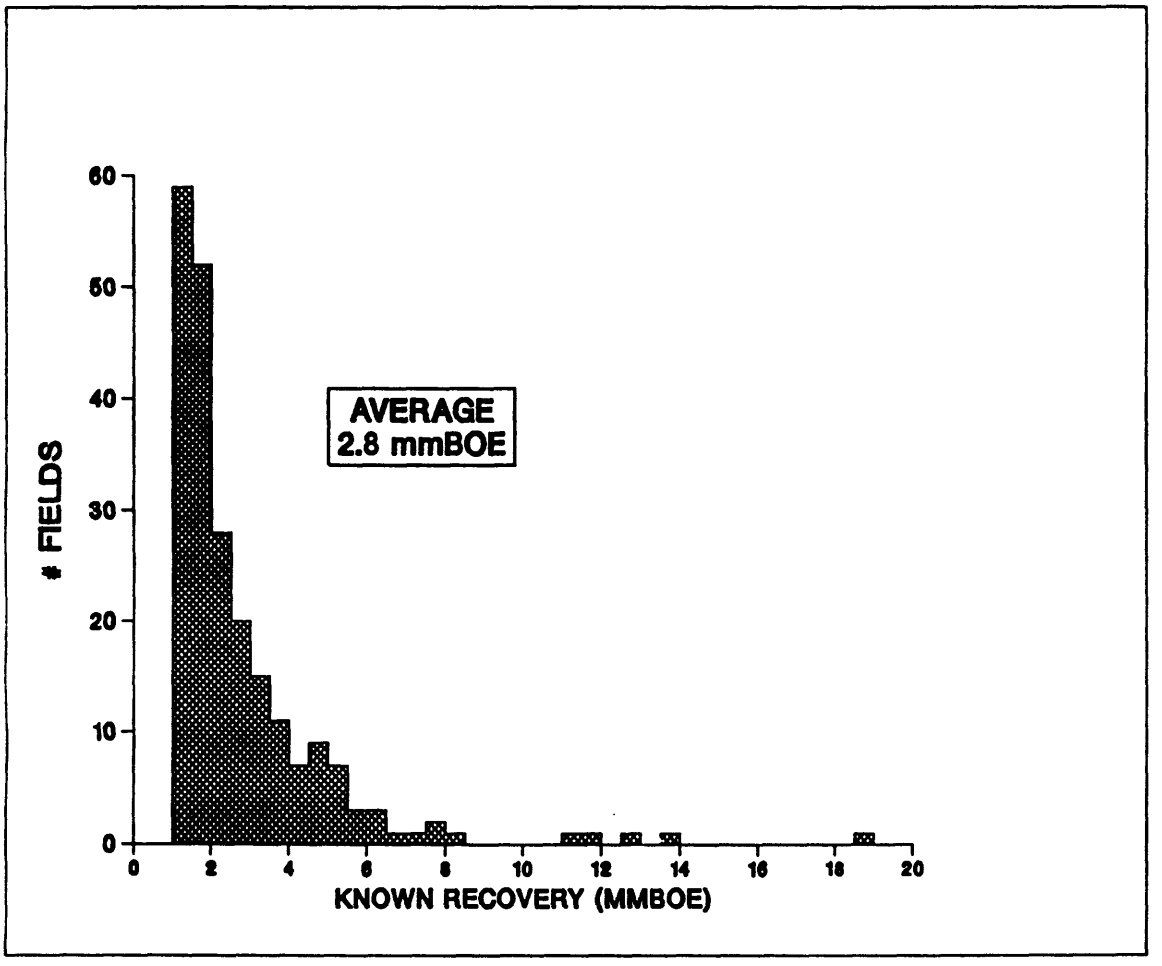


Figure 12. Histogram showing distribution of field sizes (in million BOE known recovery) for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

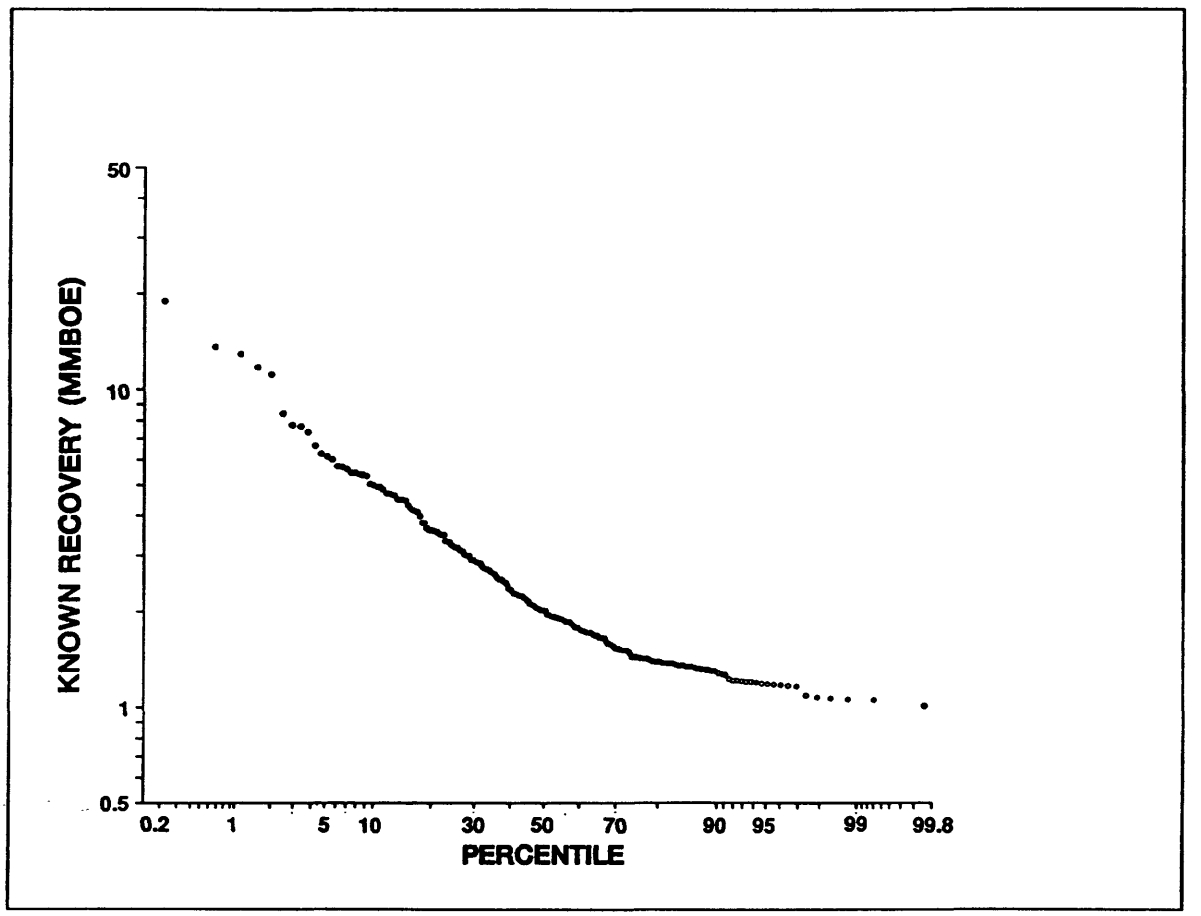


Figure 13. Lognormal plot of field sizes (in million BOE known recovery) for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play. A straight line would indicate a perfectly lognormal distribution; truncation of fields less than 1 million BOE in size causes the deflection of the trend near that size.

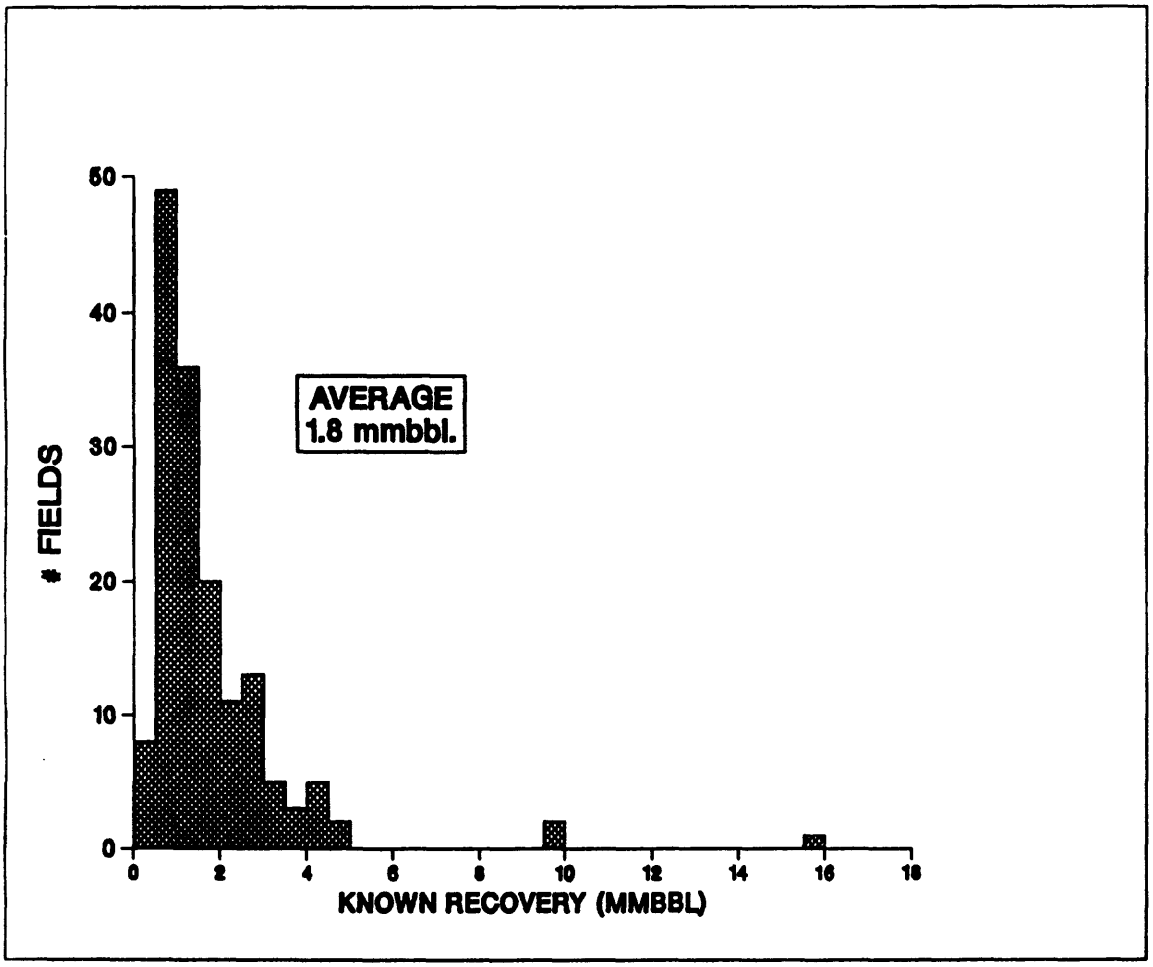


Figure 14. Histogram showing distribution of oil and mixed oil and gas field sizes (in million barrels known recovery) for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

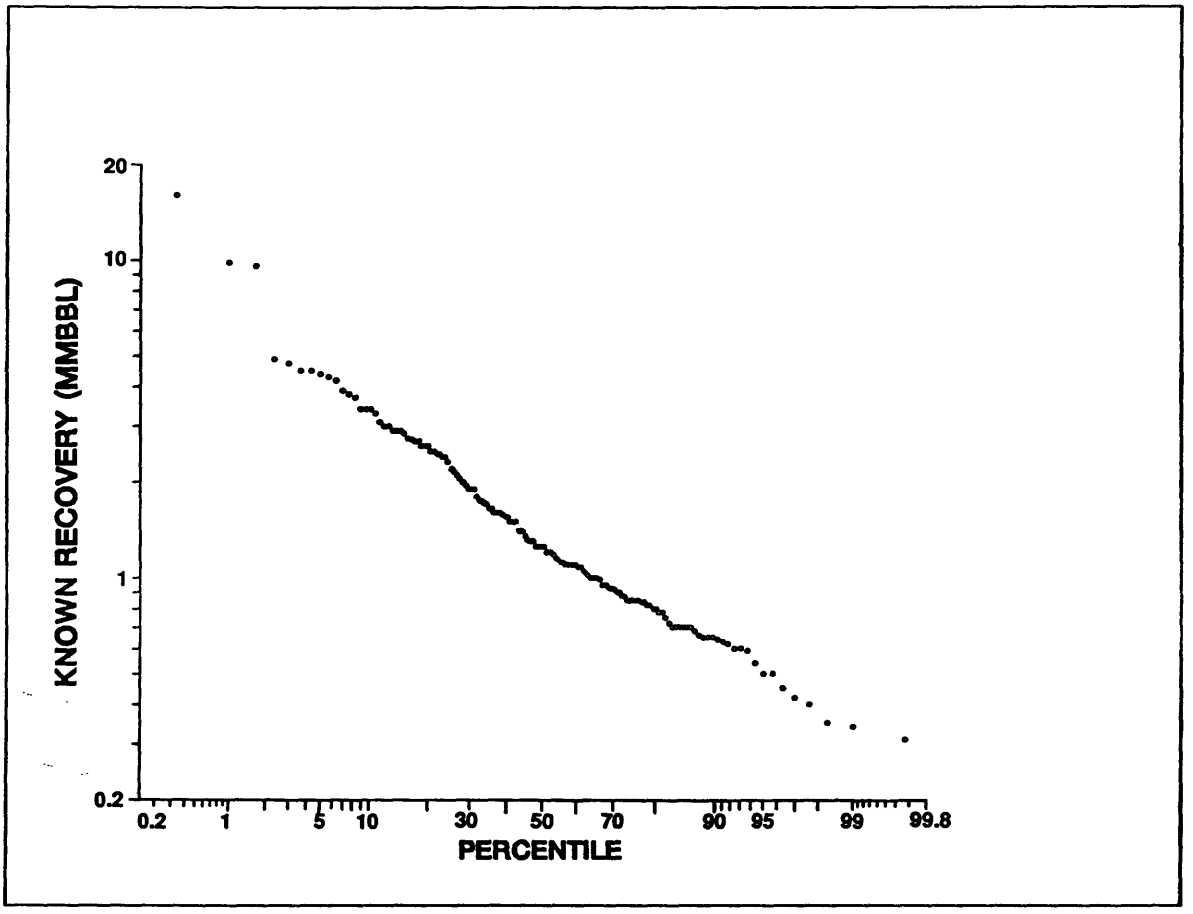


Figure 15. Lognormal plot of oil and mixed oil and gas field sizes (in million barrels known recovery) for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play. A straight line would indicate a perfectly lognormal distribution; truncation of fields less than 1 million BOE in size causes the deflection of the trend near that size.

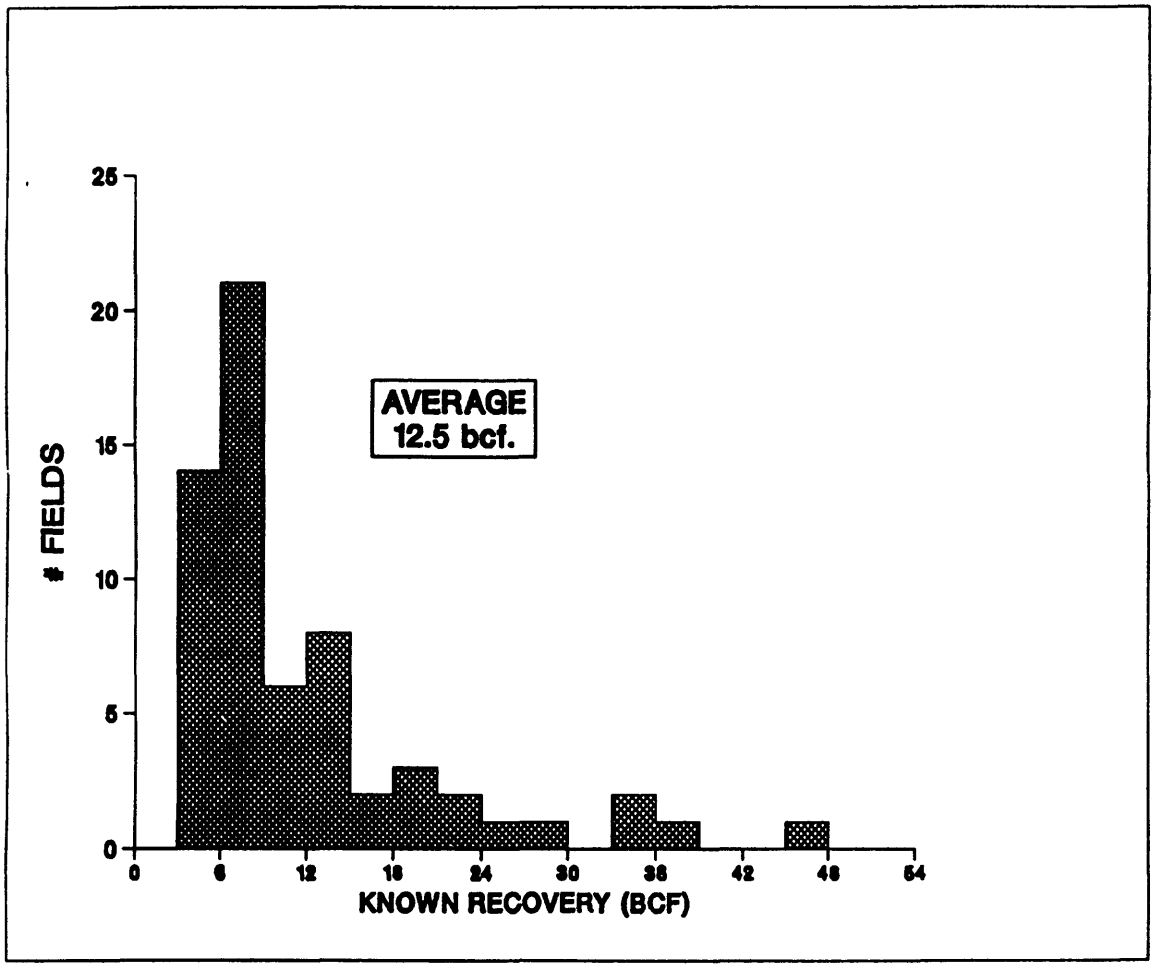


Figure 16. Histogram showing distribution of gas field sizes (in billion cubic feet known recovery) for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

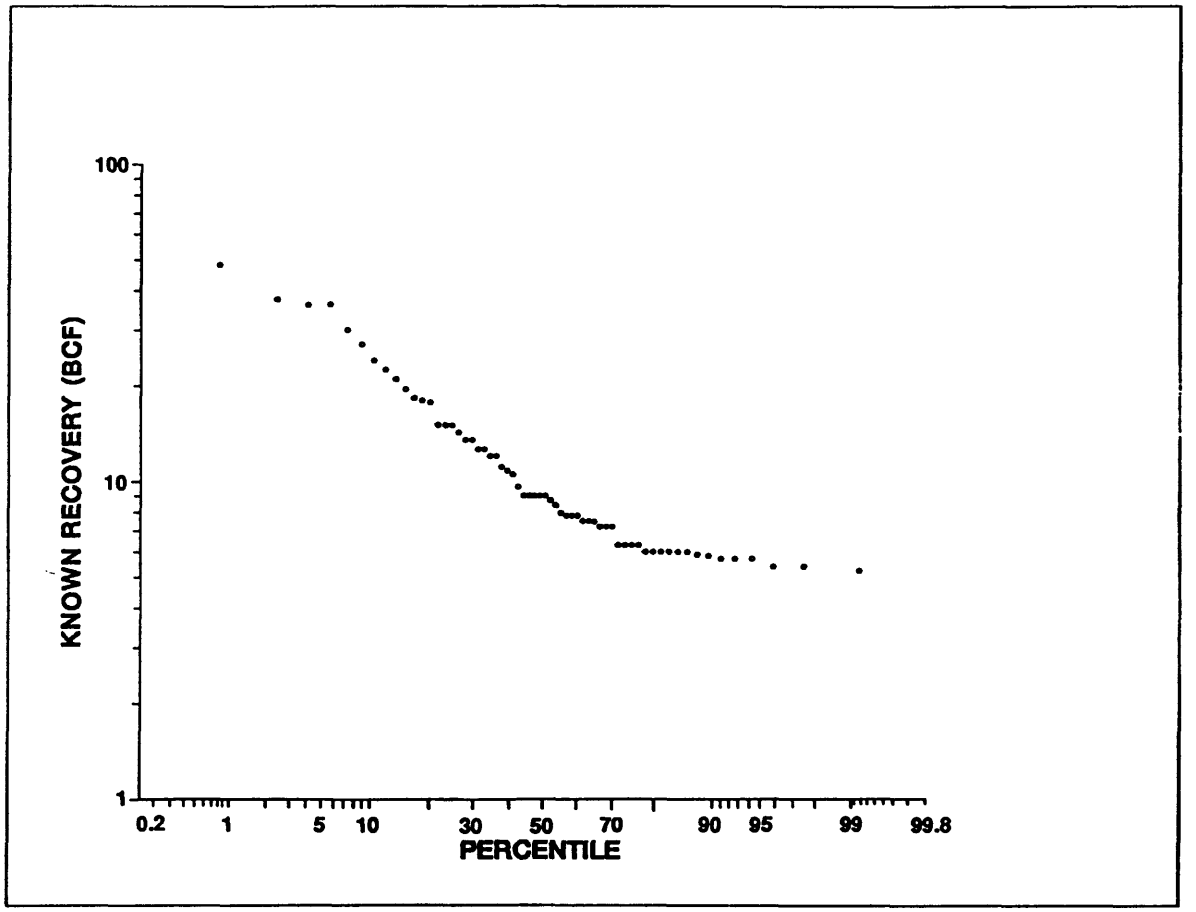


Figure 17. Lognormal plot of gas field sizes (in billion cubic feet known recovery) for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play. A straight line would indicate a perfectly lognormal distribution; truncation of fields less than 1 million BOE (6 bcf) in size causes the deflection of the trend near that size.

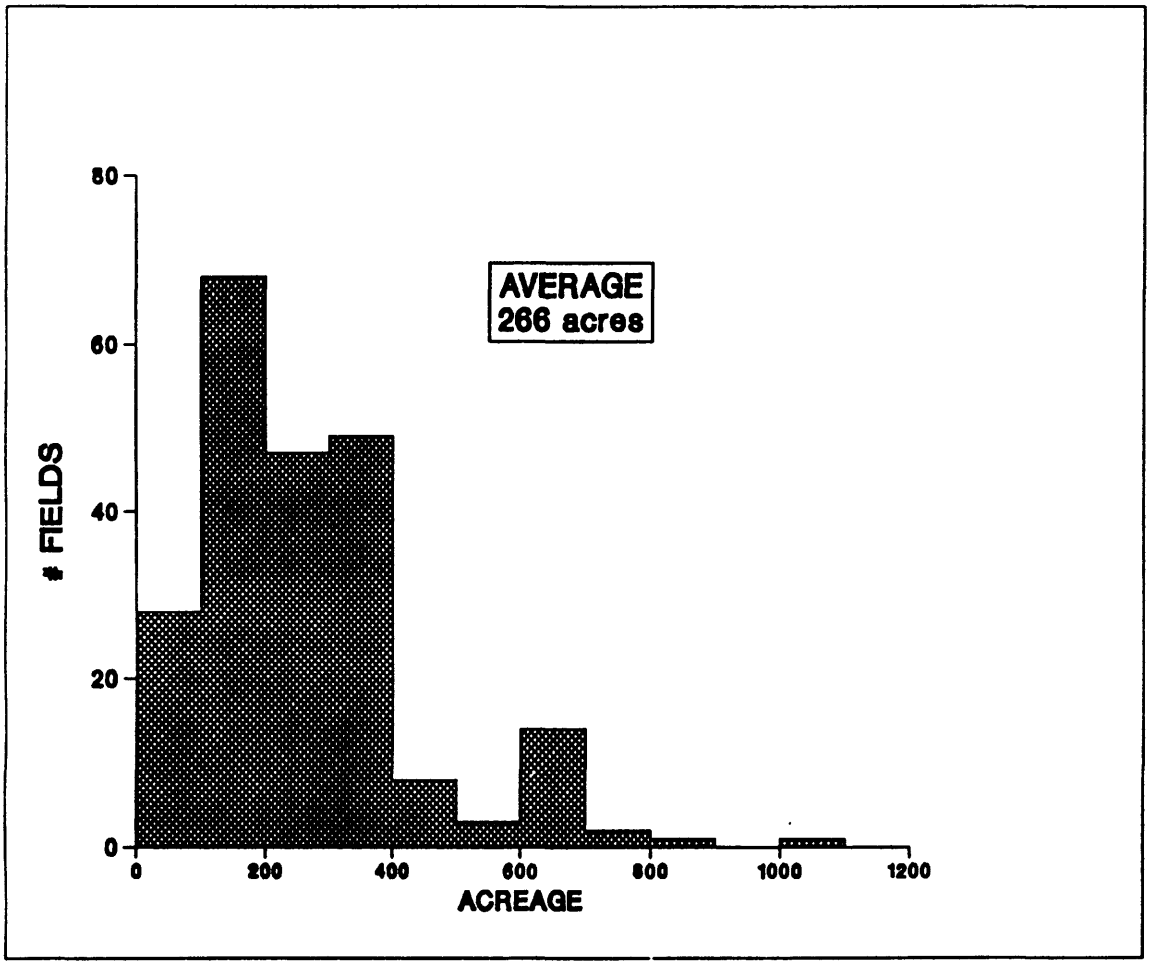


Figure 18. Histogram showing distribution of reported producing acreage for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

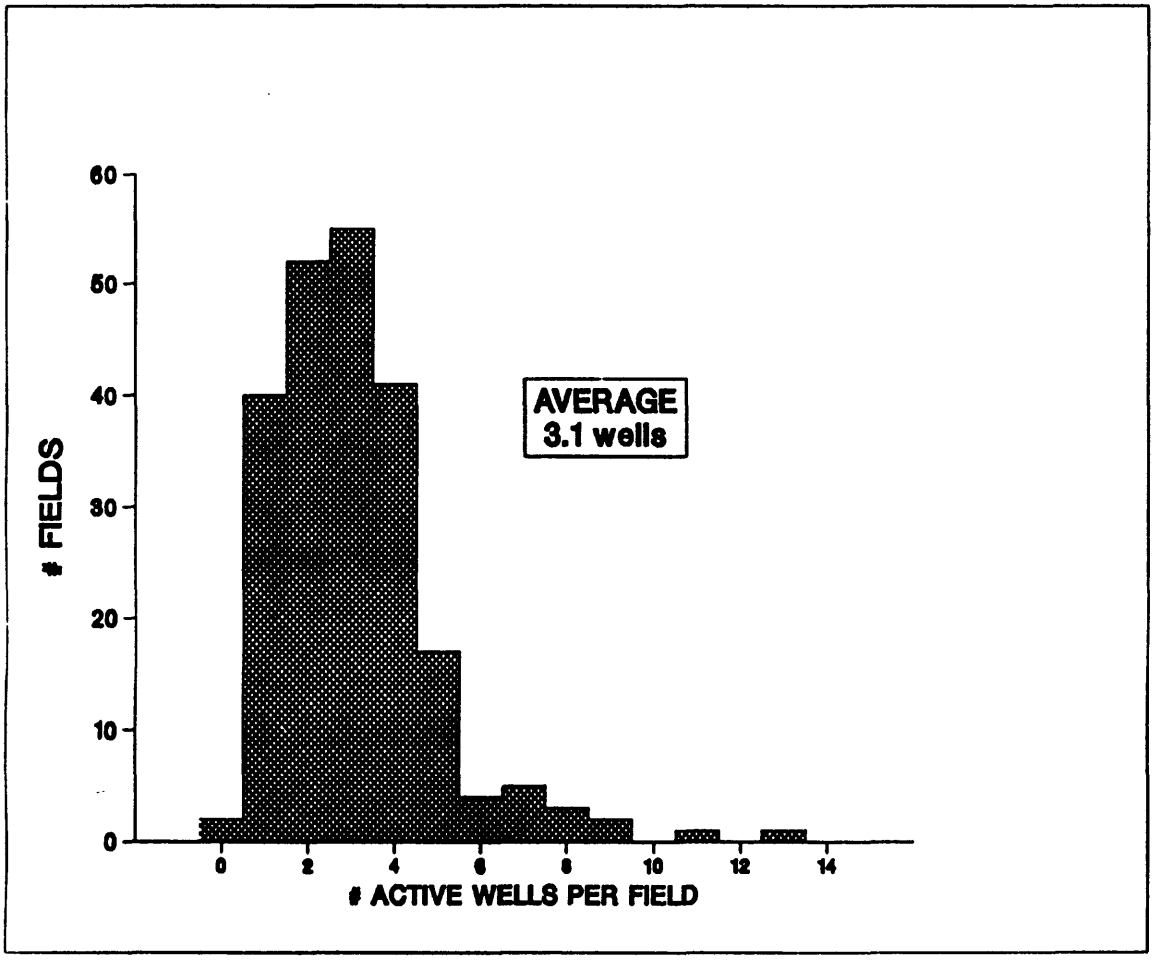


Figure 19. Histogram showing distribution of number of active wells per field for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

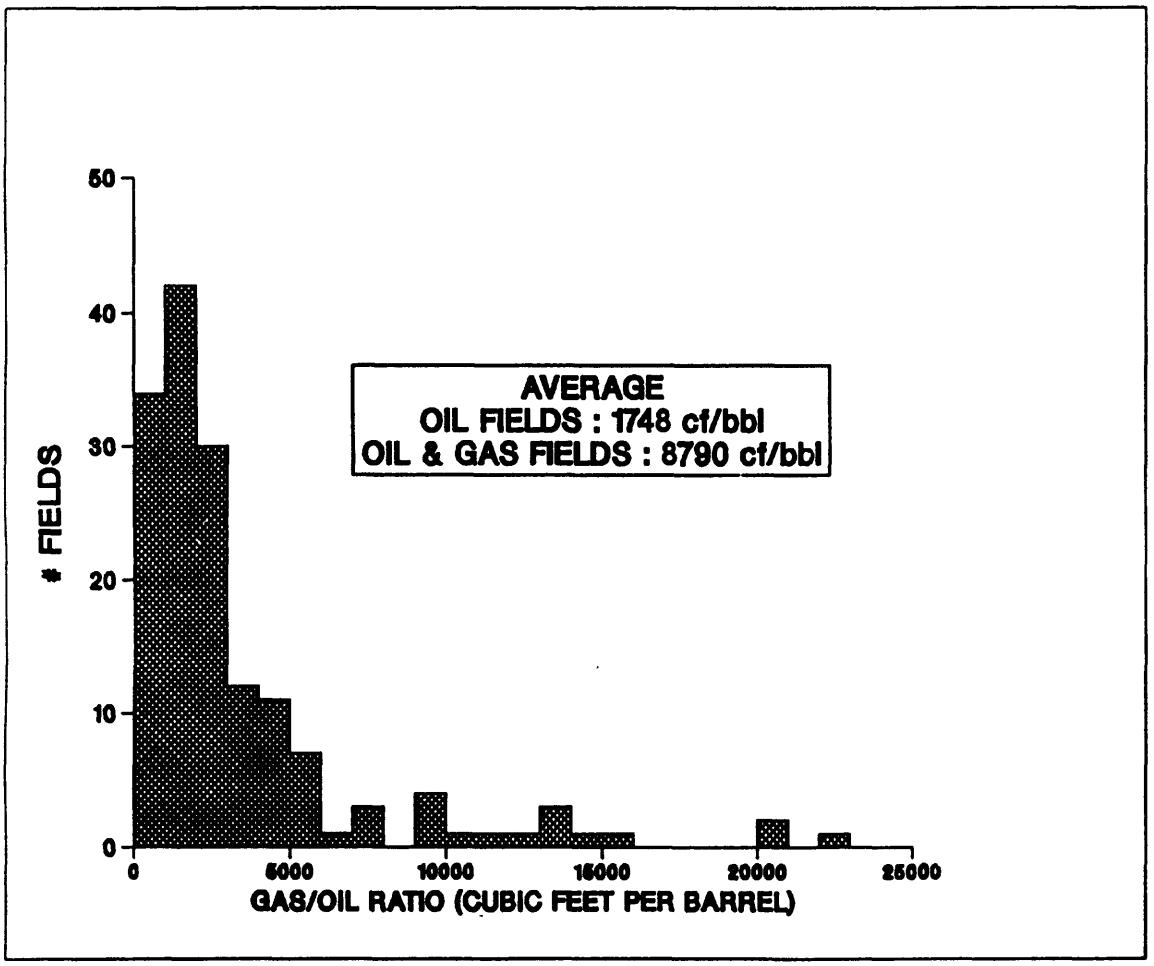


Figure 20. Histogram showing distribution of (produced) gas/oil ratio (in cubic feet per barrel) for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

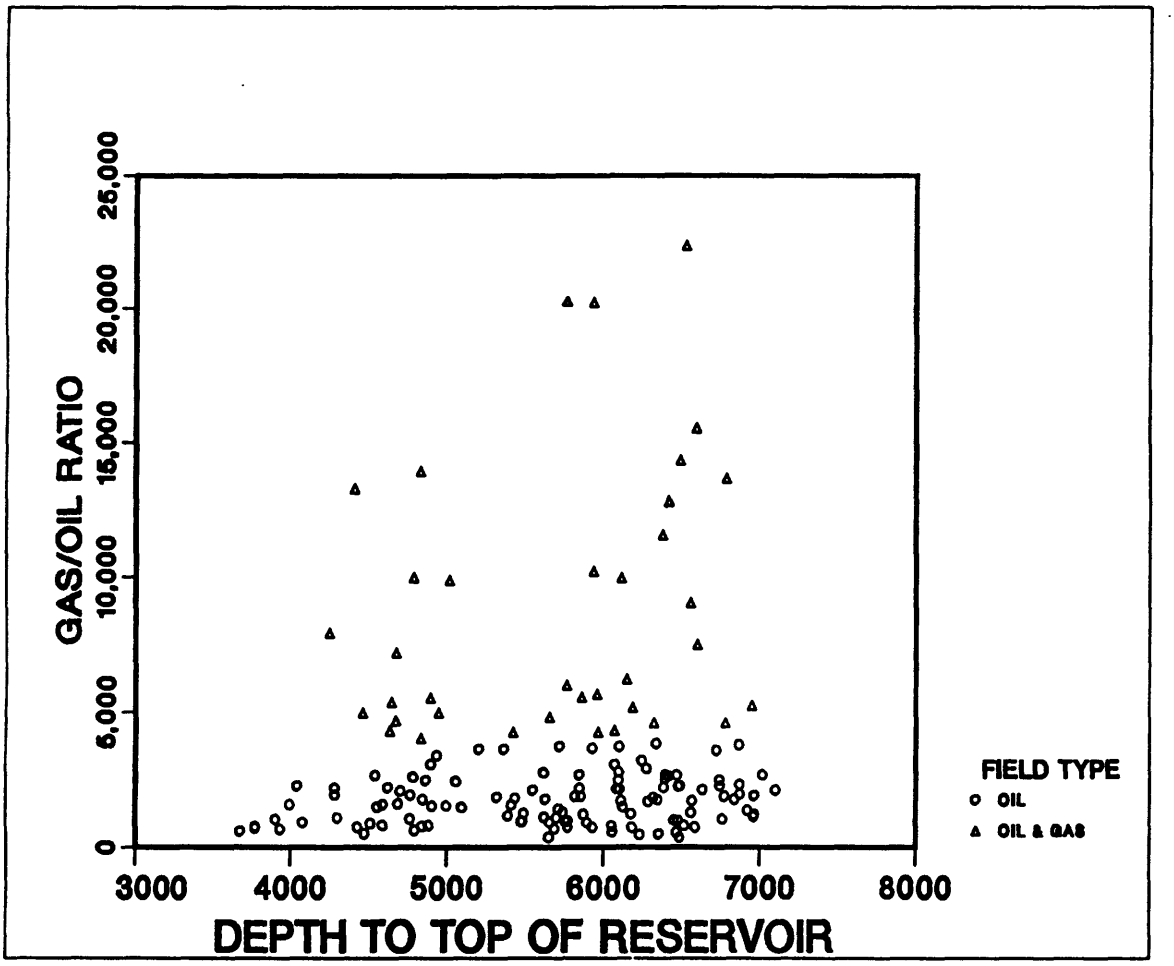


Figure 21. Plot showing (produced) gas/oil ratio (in cubic feet per barrel) versus depth (in feet) for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

Reserve/production ratios are relatively low (figures 22 and 23), averaging 4.7 for oil and 6.8 for gas.

SUMMARY

The northern Michigan Silurian reef trend is a 150 by 6 mile northeast-southwest oriented group of hydrocarbon fields producing from stratigraphic traps in reefs of Niagaran (Middle Silurian) age. The trend includes 224 fields equal to or greater than one million barrels of oil equivalent in size. The distribution of volumetric sizes of the reservoirs is roughly lognormal. Basic reservoir characteristics such as net pay thickness and acreage are also positively skewed. Reservoirs are deepest near the center of the trend and shallower to the northeast and southwest. Since 1974, there have been strong declines both in discovery rate and in the sizes of the fields found.

This study gives an example of the type of play-scale data summaries and analyses that can be generated from commercially-available data bases. These studies can provide suitable analogs for appraisal of undiscovered hydrocarbon resources.

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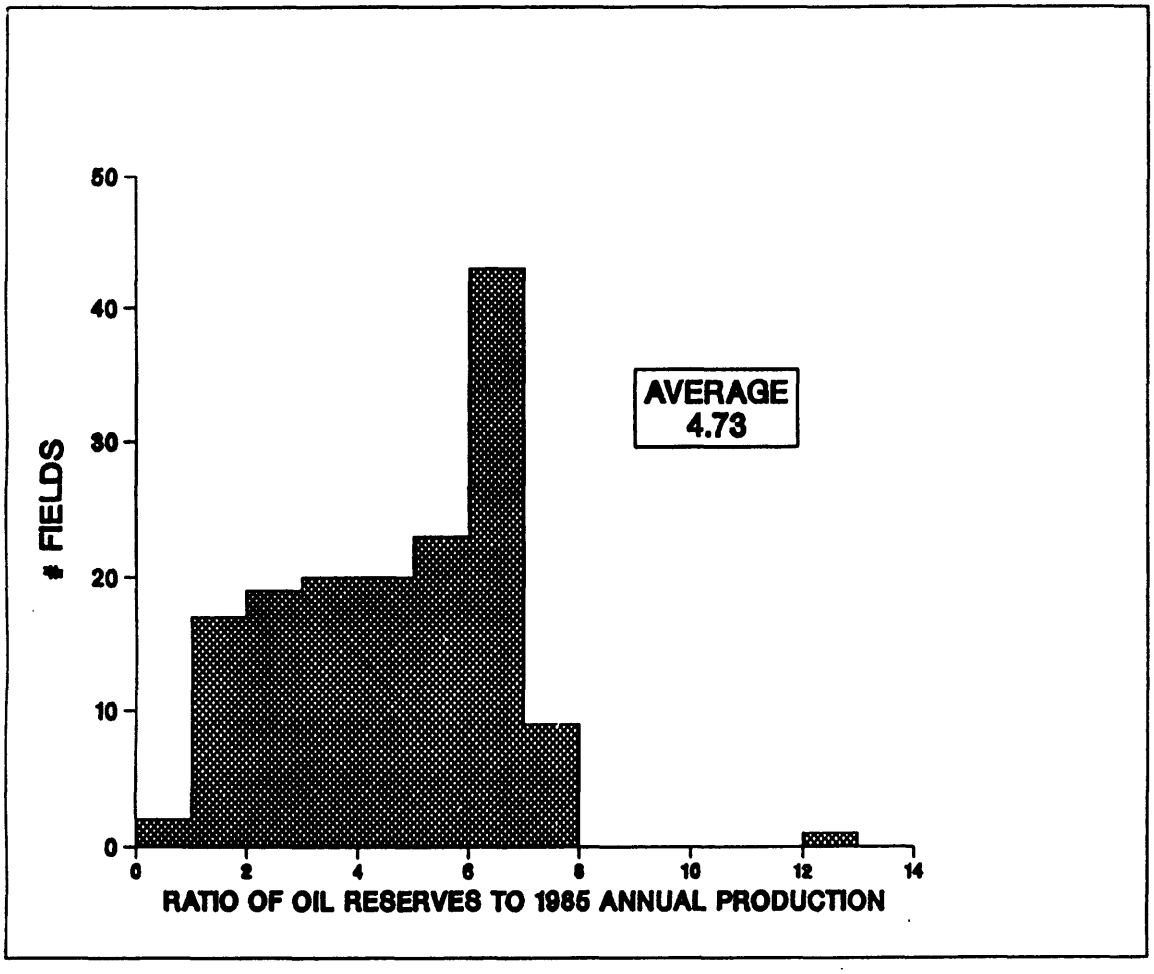

Figure 22. Histogram showing distribution of the ratio of oil reserves to 1985 annual oil production for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

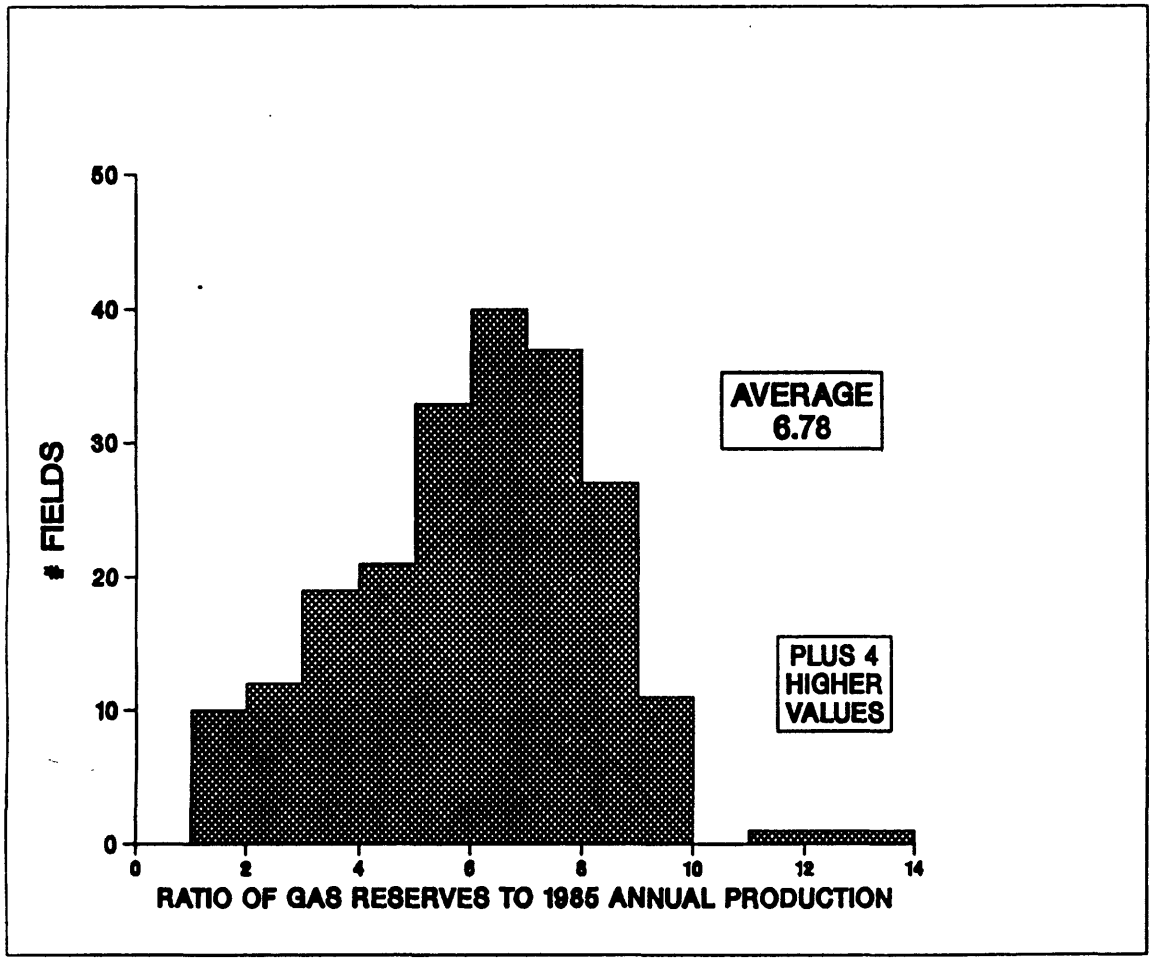

Figure 23. Histogram showing distribution of the ratio of gas reserves to 1985 annual gas production for fields of 1 million BOE or more known recovery in the northern Michigan Silurian reef play.

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