How to Look at Frontier Basins: An Example from the Canadian Arctic*

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Abstract

"What's Next" for hydrocarbon exploration in Canada will surely involve examination of opportunities in the Frontier Basins. Exploration in these basins ceased twenty years ago after most of the fields in Frontier Basins had been discovered (Meneley, 1986). Exploration is only now beginning to restart. In the meantime the logistical infrastructure to support exploration operations has largely been dismantled and old age is eating away at the experienced professionals that were once available. New ventures into the Frontier Basins of Canada need to use all of the hard won information that was acquired in order to critically evaluate the opportunities.

This paper will illustrate the steps that should be taken when evaluating any exploration area where one or more exploration cycles have previously take place. Information from previous exploration will contain critical clues that may indicate hitherto unappreciated exploration potential, or on the other hand, a warning that the future potential has already been discounted by the previous work. The steps that should be followed include:

1) The history of land acquisition or concession activity.
2) What has been the exploration history of the basin?
3) What results did the initial drilling programs achieve?
4) If exploration were recommenced in an area, what would be done differently for success?
5) Don't underestimate the effectiveness of the first round of exploration.

Figure 1 shows the geological provinces of the Arctic Islands and the wells that have been drilled. This Case Study uses the Sverdrup Basin as an example; this basin was the site of one of the most successful and comprehensive exploration programs in the Frontier basins in Canada. A careful review of the history of exploration in the basin, the geological controls on the size of hydrocarbon accumulations that were found, and the nature of future prospects is used to estimate the future potential. The newly developed Truncated Discovery Process Model (Logan, 2005) illustrates an assessment of the undiscovered gas potential in the Mesozoic sediments in the western Sverdrup Basin.

Exploration History

Pioneering surface geological work by the geological survey of Canada (Fortier et al., 1963) set the stage for the great land rush that started in 1960 and ran through to 1968 by which time almost every available acre of land, sea, and ice cap in the Canadian Arctic was held under exploration permits. The organization of Panarctic Oils Ltd. in 1968 resulted in the consolidation of a large portion of the onshore and some offshore exploration rights into a single operating entity. Following initial exploration success at Drake Point (1969) and King Christian (1970) exploration focused on the Sverdrup Basin. Panarctic developed the technology to shoot seismic on the ice and to make the velocity corrections for abrupt changes from thick permafrost onshore to no permafrost in the offshore (Acheson, 1981).

By early 1973, evaluation of drilling results led Panarctic to further narrow their focus to the western part of the Sverdrup Basin. Development of ice platform drilling technology (Baudais et al., 1976) permitted drilling, first of offshore delineation wells followed by the first wildcat well at Jackson Bay in 1976. The Arctic Islands Exploration Group was formed by Panarctic and included the holders of most of the offshore permits as well as major oil companies. This permitted the area wide exploration of the offshore Sverdrup Basin. As a result the Sverdrup Basin was explored by companies who had the freedom and expertise to select their best technical prospects and guide a well-directed, unconstrained exploration program.

There is a wealth of public domain information available on the Sverdrup Basin. Trettin (1991) presents a compilation of papers on Arctic geology, history, and resource assessment with references attached to each paper. Recent publications by Waylett and Embry, (1992) and Chen et al. (2000, 2002, and 2004) discuss the factors controlling hydrocarbon accumulations and the assessment and high-grading of exploration areas.

Results of Exploration

Figure 2 shows the 124 wells that have been drilled in the Sverdrup Basin, the discoveries of gas and oil that have been made, and the undrilled prospects that have been mapped by Panarctic Oils Ltd. (Waylett and Embry, 1992; CGPC, 2001). Sixteen gas and oil discoveries and one small oil discovery have been made in the western Sverdrup Basin and these are named on Figure 3. Collectively they contain 19.8 Tcf of Original Gas in Place (OGIP) (CGPC 2001). A small oil show was found at Romulus in the eastern Arctic.

The main reservoir is the Triassic Heiberg Formation and its lateral equivalents. The Heiberg limits are shown on Figure 2, the Heiberg is truncated at a pre-Jurassic subcrop along the southern margin of the basin and is limited by its subcrop, outcrop, or by intrusives elsewhere. Younger reservoirs have been productive along the basin axis that extends east west through Lougheed Island.

Dry natural gas is the dominant hydrocarbon, the only significant oil field was found at Cisco west of Lougheed Island. Following that success Panarctic and their partners were not successful in locating other Cisco look-alikes. A prolific source rock is present in the Middle to Upper Triassic Schei Point Group and multiple stages of hydrocarbon generation are indicated. Waylett (1990) describes some of the enigmas surrounding the generation and migration of hydrocarbons in this play.

The two largest fields at Drake Point and Hecla are on the southwest flank of the basin. These are large thin-pay fields on wrench-related structures; Hecla has a stratigraphic trap component as well. The remaining fields are all on large salt-cored structures of varying amplitudes. Diapiric salt structures that reach the surface or sea floor in the form of circular diapirs and salt walls are shown on Figure 2. Productive structures are complexly faulted and hydrocarbon loss from these features has been well documented by Waylett and Embry (1992). Traps are underfilled and as little as 10% of the trap capacity is occupied by gas. A maximum gas column of 158 m was found at Jackson Bay. This is a very 'leaky" trap environment and top-seal is a key factor that controls the size of hydrocarbon accumulations in the Sverdrup Basin. As a result of underfilling, structures have a much larger areal footprint than is indicated by the productive area. Figure 4 shows the relationship between field size and productive field area. If the structurally closed area is considered the large footprint fields would actually plot close to or above the best-fit line on Figure 4; for example Whitefish has a structural footprint of over 100 km^2. Traps are normally pressured and reservoirs range from –560 m at King Christian to –2307 m at Roche Point; there is no correlation between depth and field size.

Because of the large structural footprints early reconnaissance seismic and gravity surveys readily located the larger structures, most of which had been identified by the spring of 1973. Subsequent surveys confirmed the presence of some additional features and detailed the complexity of the known structures. There are likely many small structural closures to be found, mainly on the flanks of salt diapirs and salt walls, but it will be difficult to define large traps that can hold significant gas resources in those structural settings.

Figure 5 illustrates the exploration history in the Sverdrup Basin. Exploration proceeded in two cycles. Initially onshore drilling produced early success from 1969 through 1973, the big fields were found early and the small field at Wallis (1973) was the last onshore discovery. Unsuccessful onshore drilling continued to 1985 at a reduced rate.

Offshore drilling started in 1975 and peaked in 1982 when five offshore wells were drilled. Early success was achieved at Jackson Bay and Whitefish, but the decline set in and subsequent discoveries were smaller. The last offshore discovery was made at Cape Allison when the landholders finally drilled 1985 in order to retain a Significant Discovery License. Offshore exploration ended in 1986 due mainly to the absence of viable exploration targets. Two distinct "creaming curves" are evident on Figure 5, both the onshore and offshore components of the western Sverdrup Basin Mesozoic play have exhausted prospects for large gas discoveries.

With the information discussed above in hand the issue of assessing undiscovered resources can be addressed. In this example the assessment of undiscovered gas resources in Mesozoic reservoirs in the western part of the Sverdrup Basin will be dealt with.

The Truncated Discovery Process Model (TDPM)

The Truncated Discovery Process Model was developed by Ken Logan (2005) at TransCanada Corporation and is presented here with their permission. While this model is mainly used for exploration plays where there are enough discoveries to provide a statistically valid sample this presentation will illustrate how it may also be applied in a frontier situation where there are few discoveries. As long as there is an adequate body of exploration history and understanding of the hydrocarbon habitat, a meaningful geologically constrained resource assessment can be made.

TDPM is a discovery process model that uses the discovered resource information from fields above the mode of the distribution, excluding "outlier" fields. Figure 6 illustrates the TDPM assessment of undiscovered gas in place and number of undiscovered fields for the Mesozoic reservoirs in the western Sverdrup Basin. In this example, gas resources in 16 fields (CGPC 2001) were considered, but the two largest fields at Drake Point and Hecla were treated as outliers, because of their size and their geology. Gas resources in all zones have been included. No conversion of oil to gas equivalent was made. A conversion was done by Chen et al. (2000) on an energy basis, but that yields totally erroneous conclusions. If oil and gas are to be combined for assessment purposes then it must be done on a hydrocarbon pore-volume basis. In this play the pore volume occupied by gas is vastly larger than that by oil. For this assessment only gas volumes are considered.

The History Match plots the time sequence Field Count against Cumulative gas in place resources (Bcf). The green points are the discovered fields in the model range. The Solver module in Excel is used to reach a minimum least squares solution for a lognormal curve fit using the TDPM parameters shown in the inset box. The magenta line shows the interpreted curve. The lognormal parameters are used to project the interpretation beyond the model range. Constraints can be placed on the TDPM variables to ensure that the answer is geologically valid. If it is not then the constraints need to be changed and the case rerun. Geological judgment always overrides the mathematical solution.

In this example the following constraints were applied. Whitefish was judged to be the only field in Class 17, there were a total of 40 pools in the model range and the value of μ was ≤ 9 to raise the total number of undiscovered fields to 300. An optimistic picture of the gas potential in the western Sverdrup Basin is presented on Figure 6.

While the undiscovered oil potential was not assessed the discovered oil accumulations are mainly occur in reservoirs above the Heiberg. They appear to be leakage from deeper reservoirs due to fracturing (Balkwill and Fox, 1982; Waylett and Embry, 1992). Biodegradation of some of the shallow oil accumulations is evident. Delineation of the Cisco oil discovery was disappointing as the field is broken up into a number of fault-bounded accumulations. The conclusions of Chen et al. (2000, 2002, and 2004) regarding oil and gas potential do not fit with the actual exploration history.

Heiberg and younger reservoirs are preserved in the vicinity of Graham Island and in the vicinity of the Romulus oil show in the eastern Sverdrup Basin. There is a large exploration target defined at Gordon Head east of Cornwall Island, but the proximity to outcrop and shallow depth of the structure downgraded this prospect while exploration was active. Follow up drilling in the vicinity of Romulus was unsuccessful and there is little room to explore in the Fosheim lowlands.

In the future, older reservoirs in the Triassic and Upper Paleozoic in the Sverdrup Basin may be viable exploration targets. A new play or plays need to be developed rather than persisting with the largely exhausted Mesozoic play.

Conclusions

1. The gas resources in Mesozoic reservoirs in the western Sverdrup Basin were found in two logistically controlled exploration cycles and each showed diminishing discoveries due to exhaustion of available exploration targets.

2. The TDPM methodology provides an excellent assessment tool that permits application of geological constraints to ensure that the assessment is based on a geologically sound basis. Both the undiscovered potential and the field sizes in which the potential is expected are clearly shown.
3. There is an excellent gas and oil source rock present in the Triassic and Upper Paleozoic. New plays, targeting older Triassic or Upper Paleozoic reservoirs, will need to be developed for future exploration programs in the western Sverdrup Basin.
4. A methodology of using exploration history, information on the results of exploration, and the controls on hydrocarbon accumulation to provide the geological basis for hydrocarbon assessment may be applied to any exploration area where discoveries have been made.

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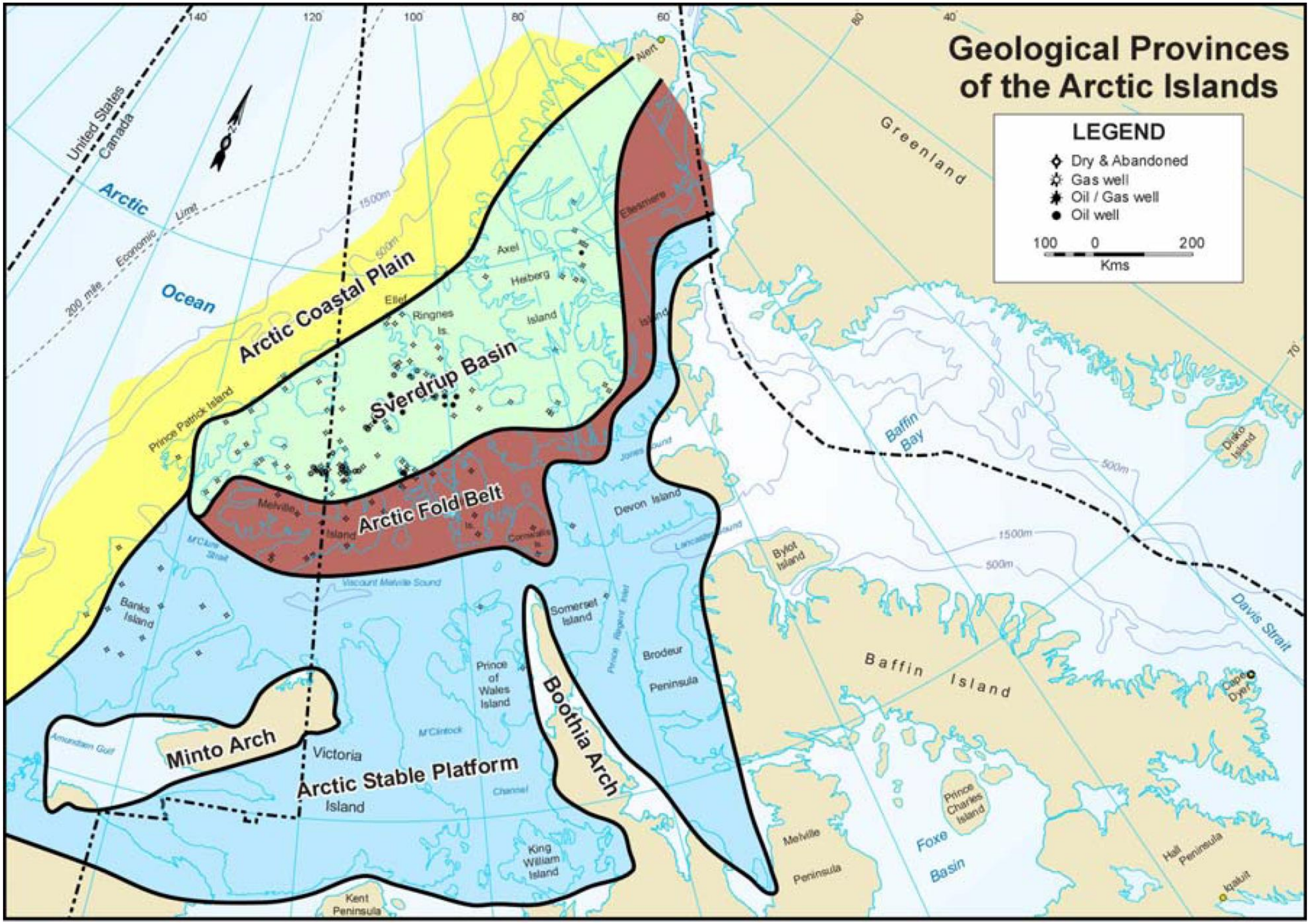

Figure 1. The geological provinces of the Arctic Islands and the wells that have been drilled.

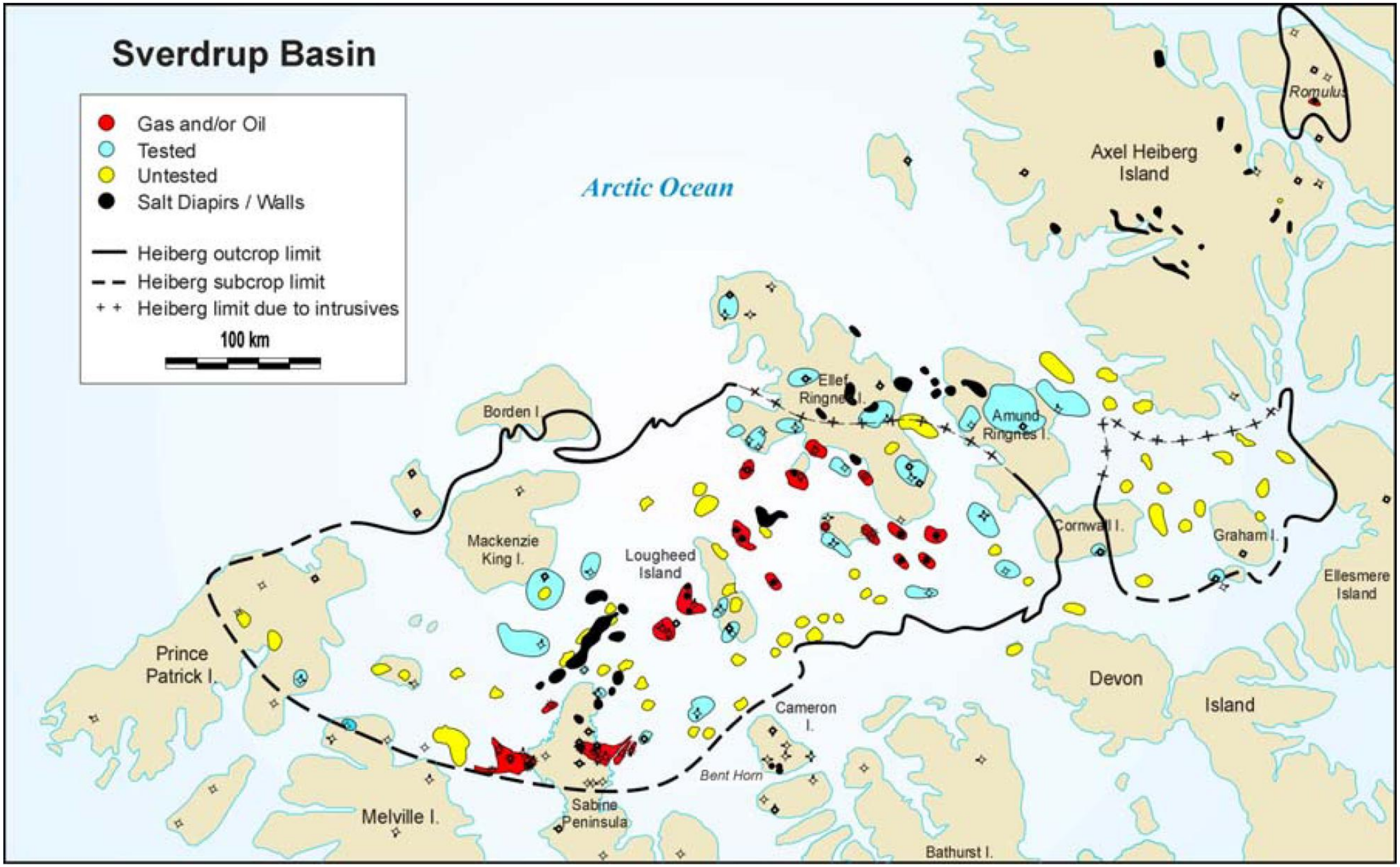

Figure 2. Petroleum activity in the Sverdrup Basin.

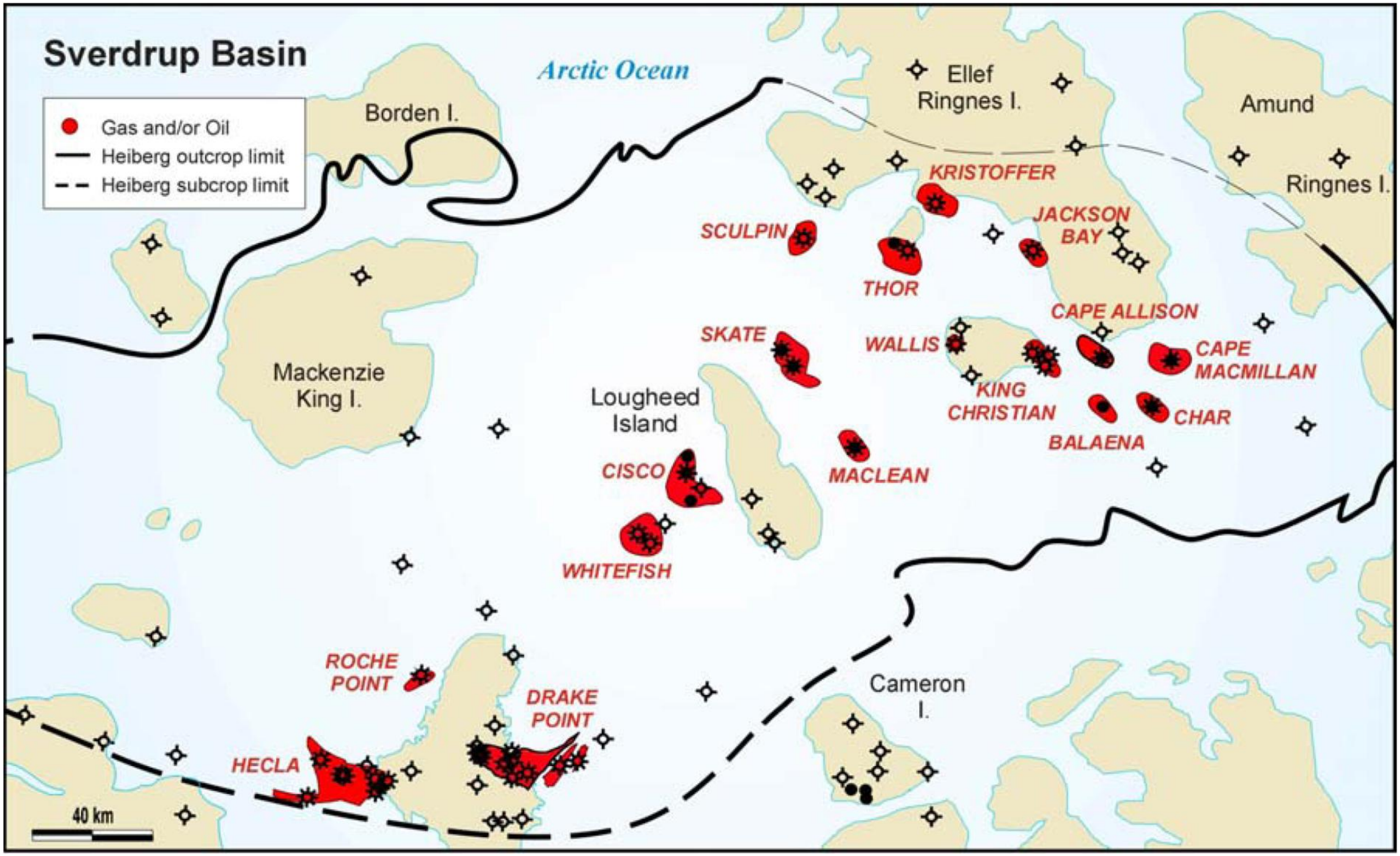

Figure 3. Oil and gas discoveries in the Sverdrup Basin.

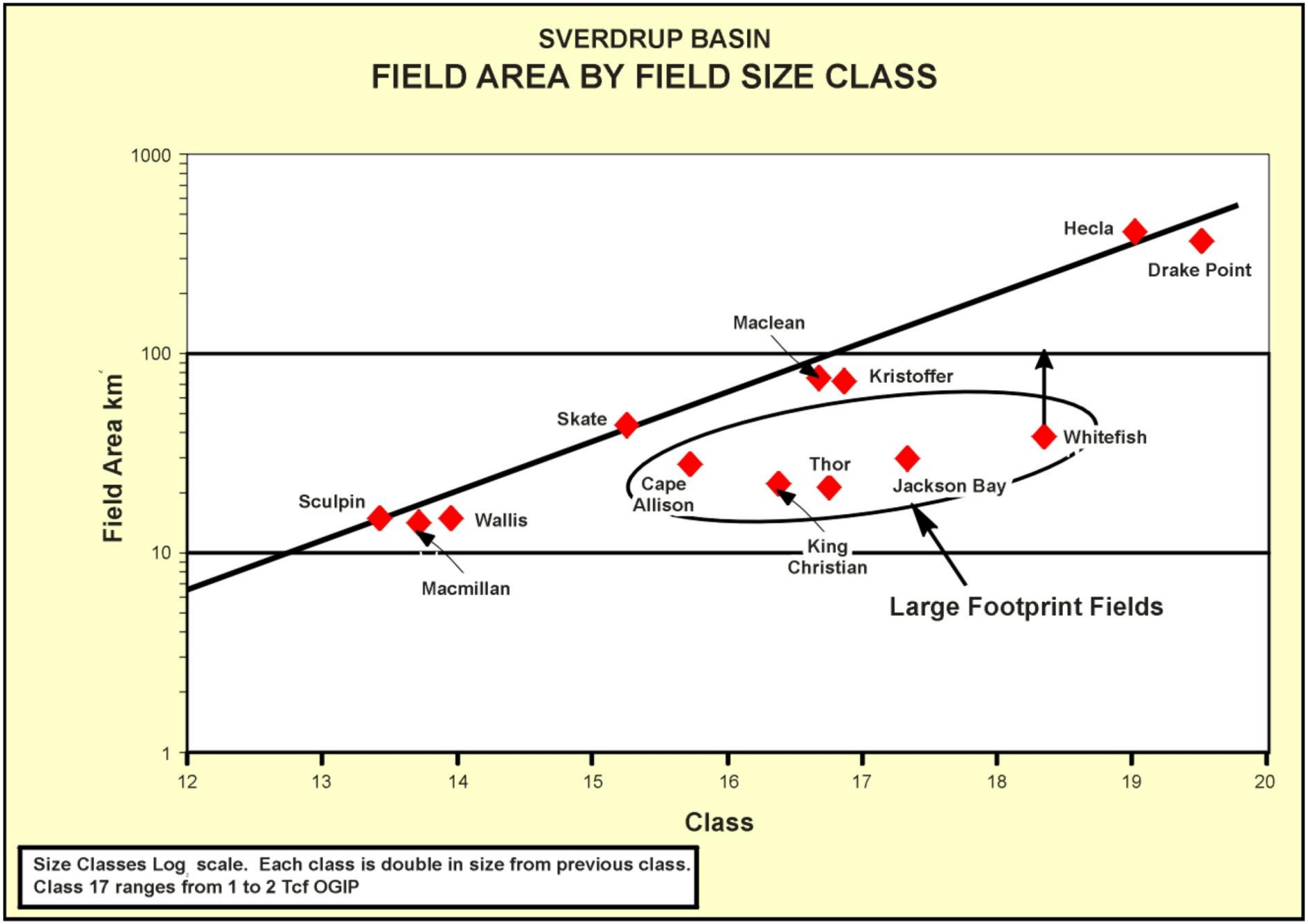

Figure 4. The relationship between field size and productive field area for the Sverdrup Basin.

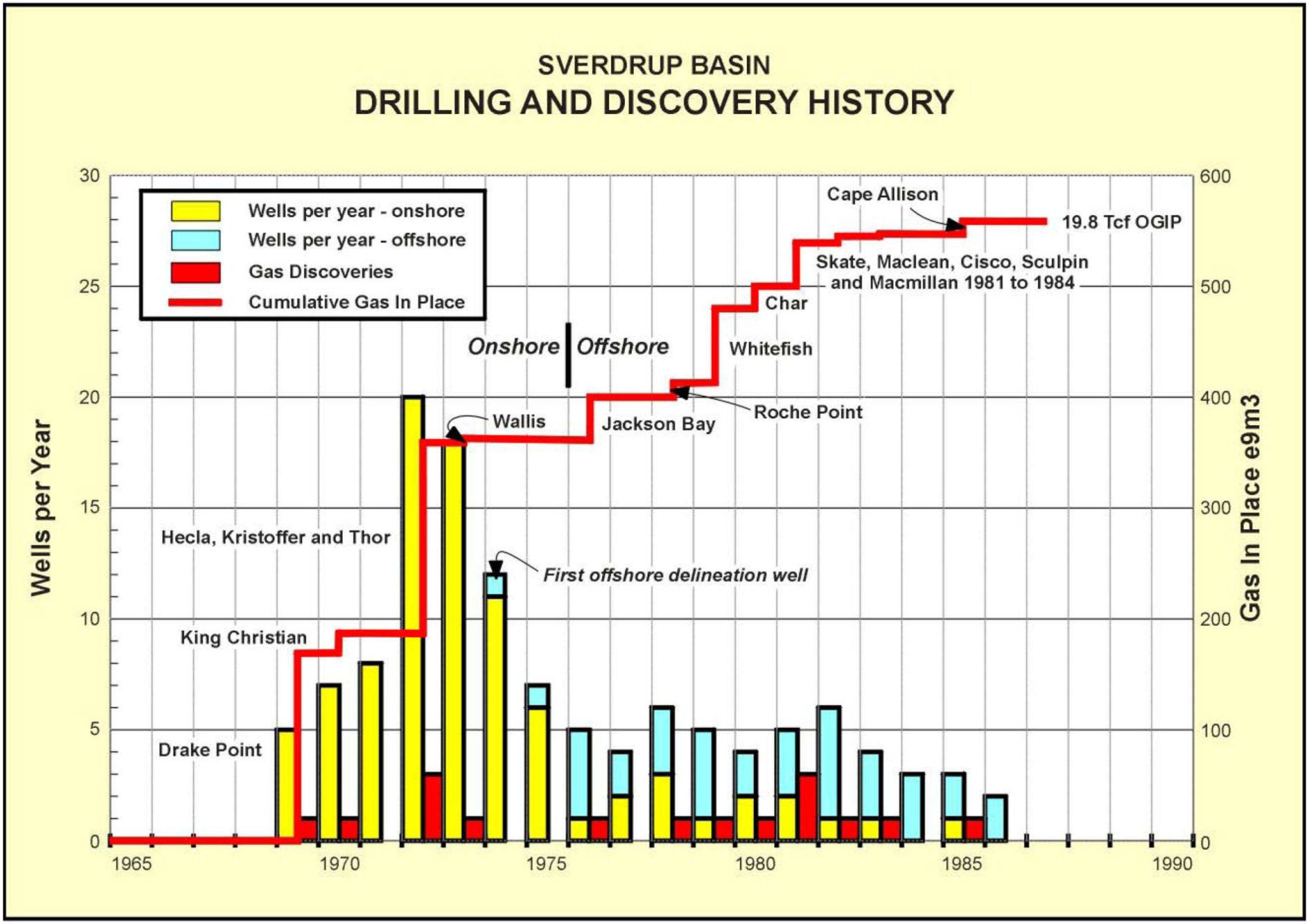

Figure 5. The exploration history in the Sverdrup Basin.

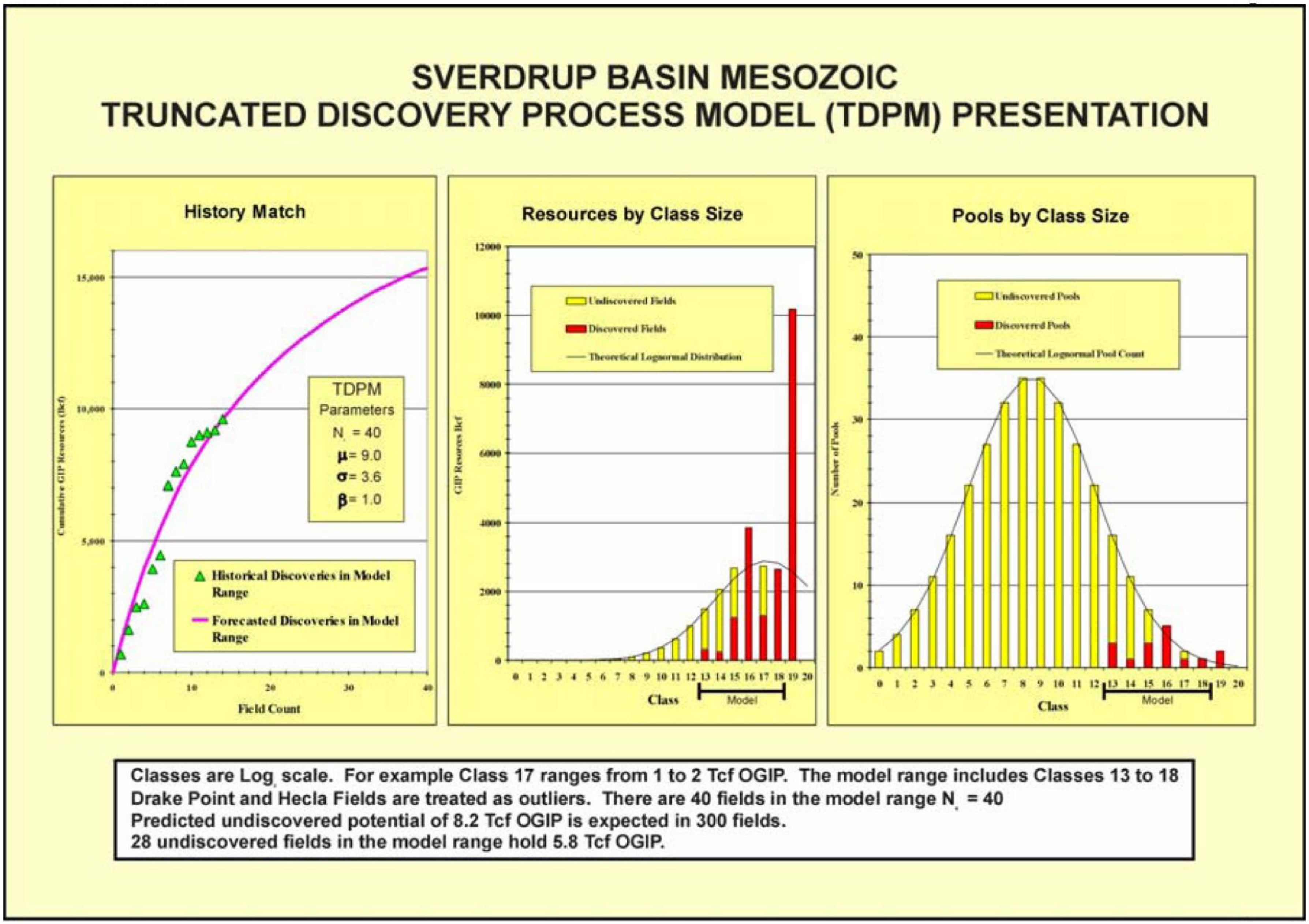

Figure 6. The TDPM assessment of undiscovered gas in place and number of undiscovered fields for the Mesozoic reservoirs in the western Sverdrup Basin.