

Petroleum Resources of Sverdrup Basin, Canadian Arctic Archipelago

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Summary

Over the past 50 years the geology and petroleum potential of the Sverdrup Basin have been elucidated through detailed stratigraphic, structural, and geochemical studies of surface and subsurface data. Fifteen gas fields and one oil field were discovered in the 1970s and early 80s and all were associated with Tertiary anticlinal structures and present in Mesozoic sandstone reservoirs. The main petroleum source rocks are Middle to Late Triassic shales.

The predominance of natural gas in the structures is interpreted to be due to a major gas release during the early Tertiary Eurekan Orogeny by way of extensive fracturing of Triassic and possibly Upper Paleozoic source strata. Previously trapped oil was flushed from the updip structures and expelled from the basin.

Major conventional and unconventional gas resources are undoubtedly present in structural and stratigraphic traps in Upper Paleozoic and Mesozoic reservoirs, in widespread and thick bituminous shales, and in large gas hydrate deposits. However, the remoteness of the basin precludes their delineation and development in the foreseeable future. Conventional oil prospects are interpreted to be present in Mesozoic sandstones in stratigraphic traps which escaped the major gas flush. Unconventional oil resources are established in the Sproule Peninsula oil sands and may also possibly occur in subsurface Carboniferous and Triassic bituminous shales.

Introduction

Sverdrup Basin, a rift/sag basin, is located in the Canadian Arctic Archipelago and extends for about 1300 km in a northeast-southwest direction and is up to 350 km wide. Maximum sediment thickness is estimated to be ~14 km and the basin fill consists of up to 5 km of Carboniferous and Permian strata (carbonates, evaporites and siliciclastics) and 9 km of Mesozoic to Paleogene siliciclastics.

In the 1973, Ken Drummond rated the petroleum potential of Sverdrup Basin as good and emphasized the presence of structures, reservoirs and source rocks as well as two recent gas discoveries (Drummond, 1973). Since that time, extensive structural, stratigraphic, sedimentological and geochemical studies have been done in Sverdrup Basin and a clearer picture of the petroleum potential of the basin has emerged. The following resource potential analysis is a qualitative one and looks at both conventional and unconventional prospects.

Basin History

Embry and Beauchamp (2008) summarized the development of the basin thusly “The basin initially developed in Early Carboniferous as a rift basin upon highly deformed Early Paleozoic strata of the Ellesmerian Orogenic Belt. The development of the basin can be broken into eight phases, each being characterized by a distinctive combination of tectonic, depositional and climatic regimes and separated by episodes of widespread uplift and basin reorganization. The Upper Paleozoic strata are up to 5 km thick and are characterized by a distinct shelf to deep basin topography. Carbonate strata dominated the shelf until Middle Permian and were supplanted by siliciclastics and chert in Middle and Late Permian when the climate cooled. Triassic siliciclastics are up to 4 km thick and they filled the deep, central basin by Late Triassic. From latest Triassic to earliest Cretaceous the basin was occupied by shallow siliciclastics shelves and up to 2 km of strata accumulated. Renewed rifting in Early Cretaceous resulted in a thick succession (2 km) of Early Cretaceous nonmarine to shallow marine strata with units of basalts in the northeast. Widespread diabase sill and dyke intrusion, likely related to the Alpha Ridge Plume and the opening of the Amerasia Ocean Basin, occurred at this time. Following an interval of low subsidence and low sediment supply in the Late Cretaceous, the basin began to be deformed in earliest Paleocene by the Eureka Orogeny driven by the counterclockwise rotation of Greenland. Local foreland basins developed and contain up to 3 km of Paleocene–Eocene strata. In Eocene the basin was uplifted and deformed by faulting and folding with deformation progressing southwestwards.” It must also be noted that a thick halite and anhydrite unit was deposited over much of the basin in Carboniferous and is the source of many salt structures which have been growing from Permian to present.

Reservoirs and Source Rocks

Numerous Mesozoic sandstone units occur on the basin margins and a few extend across almost the entire basin. These strata are porous and permeable in many areas and are potential reservoir rocks. Porosity is also present Upper Paleozoic siliciclastics and in thick carbonate successions. Middle to Late Triassic bituminous shales are widespread over the basin and are the established source for most, if not all, the discovered hydrocarbons. Highly bituminous (40% TOC), Early Carboniferous shales of lacustrine origin are hypothesized to be present in the central portion of the basin and in isolated lows along the flanks of the basin. Additional source rocks may be present in Upper Paleozoic basinal strata.

The Triassic source strata are in the oil window in the western and southeastern portions of the basin but are overmature in the central area. The strata began generating hydrocarbons in the mid-Cretaceous and continue to do so. The Upper Paleozoic source strata are all overmature and may well have started generating hydrocarbons as early as the Triassic.

Discovered Conventional Resources

Exploration in the Sverdrup Basin began in 1968, soon after the formation of Panarctic Oils. From 1969 to 1985 120 wells were drilled in the basin. Fifteen gas fields and one oil field were discovered in Late Triassic to Late Jurassic strata and in place reserves are estimated at $500 \times 10^9 \text{ m}^3$ of gas and $294 \times 10^6 \text{ m}^3$ of oil (Chen et al, 2000). Numerous oil and gas shows were encountered at numerous stratigraphic levels from Carboniferous to Cretaceous in numerous wells.

Conventional Prospects

Numerous Tertiary anticlines remain untested and Chen et al (2000) estimate the ultimate resource in this play to be $1242\text{-}1343 \times 10^9 \text{ m}^3$ of gas and $540\text{-}882 \times 10^6 \text{ m}^3$ of oil. Embry (2011) has discussed the potential for oil prospects in stratigraphic traps involving Mesozoic sandstones. Given the widespread and prolific Triassic source strata and the numerous and diverse potential stratigraphic traps, a large conventional oil and gas resource may well lie waiting to be discovered. Stratigraphic plays in Late Paleozoic carbonates and siliciclastics are also likely present and given the overmaturity of the strata, gas would be the expected hydrocarbon in most cases.

The presence of live oil and oil staining in many of the structures in the western Sverdrup indicates that the structures once contained substantial oil reserves. It is hypothesized that in the eastern and central Sverdrup Basin large quantities of gas were released from overmature Triassic and older shale units by way of extensive fracturing during the Eurekan Orogeny. The gas would have migrated southwestward into growing structures and displaced oil which had been trapped earlier when the source beds were in the oil window. The only major oil field found so far in a Tertiary structure occurs at the basinward pinchout edge of the Awingak sandstone and it likely escaped the main gas flush. Given this scenario, the best oil prospects are those in stratigraphic traps.

Unconventional Hydrocarbons

An oil sands deposit in Early Triassic sandstones was discovered on the basin margin on Sproule Peninsula, Melville Island in 1962 and in place reserves are estimated at up to $16 \times 10^6 \text{ m}^3$ of oil (Trettin and Hills, 1966). This may represent the only vestige of a huge volume of oil flushed from the basin in the early Tertiary.

Unconventional oil in the form of liquids associated with shale gas may well occur in the thick Middle-Late Triassic bituminous shales in the western Sverdrup. Early Carboniferous bituminous shales along the southern basin margin also have potential for liquids. The Triassic shales also have potential for huge shale gas reserves given their extent, thickness and organic carbon content. Finally, very large reserves of gas hydrates are also present in Sverdrup Basin (Majorowicz and Osadetz, 2001).

Conclusions

The Sverdrup Basin likely harbours extremely large natural gas resources in both conventional (anticlines, stratigraphic traps) and unconventional (shale gas, gas hydrates) reservoirs. Much of the oil generated by the Triassic source rocks likely was flushed from the basin by an early Tertiary gas migration related to fracturing and uplift of overmature Triassic source rocks in the eastern and central portions of the basin. Large oil fields may be present in the western Sverdrup Basin in stratigraphic traps associated with marginal unconformities, basinward facies changes, and pinchouts on the flanks of salt domes.

The remoteness of the basin precludes any active exploration for and exploitation of these resources in the foreseeable future.

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