The Carboniferous-Permian Reef Play in the Sverdrup Basin: Dare to Dream

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Summary

Of the hundreds of reefs known from outcrops of the Sverdrup Basin, only a handful can be shown to have a genuine reservoir potential. Secondary dolomitization is key to turning tight mud- and cement-dominated structures into potential reservoirs. The best prospective targets are the flanks of Lower Permian buildups that recorded the transition from evaporite to open-marine sedimentation along the southern margin of the Sverdrup Basin.

Introduction

Carbonate reefs spanning the entire Phanerozoic time scale form excellent reservoirs on most continents. From the Devonian stromatoporoid reefs of Alberta to the Cretaceous rudest reefs of the Middle East, carbonate buildups of various kinds and shapes have been the focus of exploration, sometimes with remarkable results. Late Paleozoic reefs are no exception: the large reefs of the Caspian Sea or the Delaware Basin are examples of how the right biota, fabric and diagenetic overprint can result in superb reservoirs.

There are literally hundreds, if not thousand of Late Paleozoic reefs of various size and shape in the Sverdrup Basin of the Canadian Arctic Archipelago. None of them were primary targets during the first round of exploration in the Arctic from the late 1960s to the mid 1980s, as industry focused on Mesozoic clastic plays in large salt-cored anticlines. Yet, major discoveries were made in reef structures of the same composition and age all along the Russian platform and Uralian Through, as far north as Timan-Pechora and the Barents Sea. A number of age-equivalent reefs in the Norwegian Barents Sea and Finmark Platform were the target of exploration but with no success (Elvebakk et al., 2002).

One key aspect to consider is the presence of an excellent source rock all along the Uralian Trough - the Devonian Domanik facies - and the lack thereof in the Norwegian Barents Sea. The same is true for the Sverdrup Basin, where reef reservoirs would have to be charged by a non-Domanik source rock, possibly the lacustrine oil shales of the Emma Fiord Formation, or the Devonian Cape Phillip Formation, or a yet unknown Carboniferous or younger source rock. The presence of dead oil in some buildups, however, does indicate that hydrocarbons migrated into these structures at some time.

Method

This paper provides an overview of the different types of reefs encountered in the Sverdrup Basin (Fig. 1), with an assessment of their potential as a petroleum play. This synthesis is based on more than 25 years of surface and subsurface investigation by the first author, complemented by the recent graduate research studies of the second and third authors.

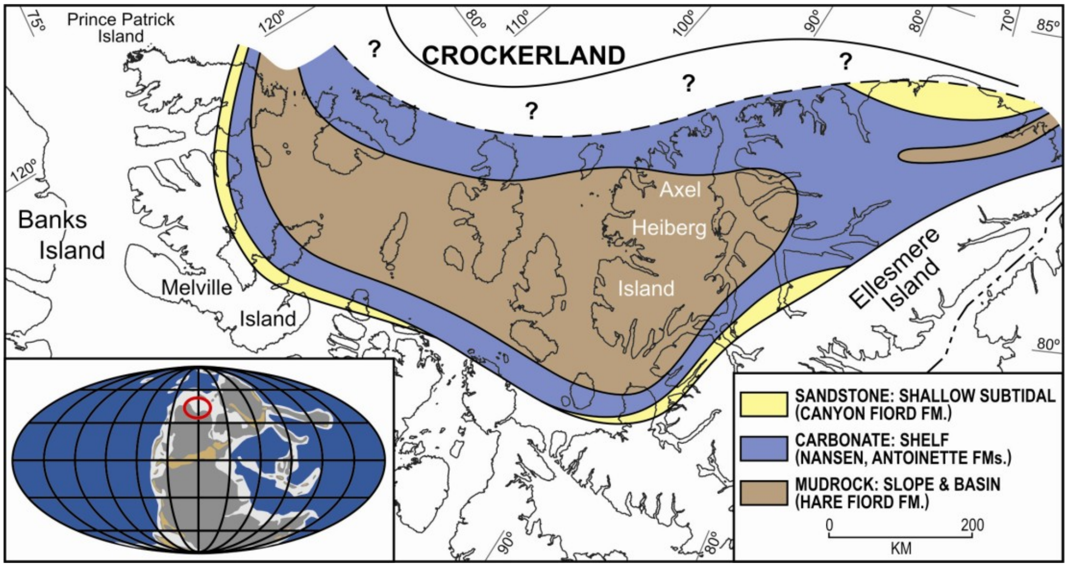

Figure 1. Late Carboniferous paleogeography of Sverdrup Basin

Sverdrup Basin

The Sverdrup Basin is a large rift-originated Carboniferous to Cenozoic depocentre in the Canadian Arctic Islands that was, from the Pennsylvanian onward, connected with the Barents Sea area to the east and Panthalassa to the west (inset in Fig. 1). Following an initial horst and graben rift configuration, a thick shelf succession developed at the periphery of a large central, deep basin (Fig. 1). The shelf was carbonate and chert-dominated up until the latest Permian and clastic-dominated thereafter. Reefs developed across the depositional spectrum of the shelf, from the Bashkirian (early Late Carboniferous) to the Kungurian (late Early Permian). No reef occurs in the Middle and Late Permian succession due to cooler water conditions. Probably upward of 1000 reefs exist in the Sverdrup Basin along the peripheral shelf which has a circumference of nearly 3000 kms. Of these, about 500 are known from the outcrop belts on Ellesmere and Axel Heiberg islands, which is a window in only a fifth of the peripheral shelf. These reefs are grouped into eight categories based on their stratigraphic position, main biota, size and shape, as shown in Table 1.

Carboniferous and Permian Reefs

Reefs of the Sverdrup Basin range in height from 5 m or less to nearly as much as 1 km, and in width from tens metres to tens of kms. The largest known reef structures form a Late Carboniferous shelf margin reef tract that extend uninterrupted for over 200 kms on NW Ellesmere Island. The smallest buildups are patch reefs that formed in mid- to inner-shelf settings. Some reefs grew as keep-up reef-mounds during the base level rise before they were drowned. Others prograded laterally over large distances during base level stillstand or fall as they ran out of accommodation space. Others recorded an initial agradational keep-up phase (TST) followed by a progradational build-out phase (RST).

The reef biota comprises either a cool-water heterozoan assemblage (bryozoan, sponge) or a photozoan warm-water assemblage (phylloid algae, *Palaeoaplysina*, dasycladacean algae). Whether cool or warm, shallow or deep, early diagenetic submarine cementation is pervasive in the form of fibrous and radiaxial cement (former high Mg calcite) and, in the case of Bashkirian and early Moscovian reefs, botryoidal calcite fans (formed aragonite). Regardless of the biota, lime mud is the principal constituents of most buildups indicating that they accumulated below fair-weather wave base, in contrast to modern reefs which build up to sea level. Abundant lime mud and pervasive submarine cementation combined to leave very little primary porosity, which is usually occluded by later burial phases. Therefore most reefs are tight and less than ideal targets for exploration. Exceptionally, reef flanks are often composed of coarse skeletal material originated on the reef crest transported along inclined flanks.

Fortunately, many reefs were subjected to dolomitization and porosity enhancement, which led locally to a vuggy, interconnected fabric with reservoir quality. Bitumen-stained pore spaces and dead oil locally occur, suggesting that hydrocarbon, from unknown sources, did migrate into some of the reefs. Dolomitization occurred either locally as pods and lenses of possible hydrothermal origin, to more pervasive reef flank dolomitization in proximity of evaporite deposits (Otto Fiord, Mount Bayley), or regional dolomitization, such as on northern Hvitland Peninsula, Ellesmere Island, the origin of which is unknown.

The best reef play is that provided by the Tolkien and Simpson reefs of NW Ellesmere Islands (Beauchamp and Olchowy, 2003; Wamsteeker et al., 2009). These reefs are complex reef-mounds characterized by a mud mound core, that recorded an initial base level rise, followed by extensively prograding flanks with coarse-grained skeletal material, recording base level stand still (Fig. 2). A later base level fall led to karstification and porosity-enhancing diagenesis. These buildups mark the transition from restricted evaporative to open marine carbonate sedimentation along the northern margin of a major depocentre along the southern Sverdrup Basin. Reflux of evaporative brines led to the early dolomitization of the reef flanks, resulting in a porous fabric with reservoir quality. The reef flanks are here clearly a better target than the reef crest of core (Fig. 2).

Conclusions

The Sverdrup Basin comprises more than 1000 reefs strewn around the basin's northern and southern periphery. Of these, very few have a genuine reservoir potential. Notwithstanding the absence of a contemporaneous or older source rock of the quality of the Domanik facies of the Uralian Trough, the best prospects for future discoveries are the large complex reef mounds that mark the transition from restricted to open-marine deposition west of Tanquary Fiord – the Tolkien and Simpson reefs. These reefs can be projected into the subsurface to the west. Comparable buildups in similar settings may also occur along the northern margin of the Sverdrup Basin, as well as in the Barents Sea.

#	Age (name)	Formation	Setting	Type	Height (width)	Main biota	Porosity (type)
1	Bashkirian	Otto Fiord	4th order TST Carbonate-evaporite cycles	Patch reef	15-20 m (50-100 m)	Tubular algae (donezellids)	Common, (vuggy dolomite)
2	Early Moscovian (Tellevak)	Hvitland Peninsula	2nd order TST keep-up shelf to slope	Reef-mounds	150-500 m (0.5-2 km)	Bryozoan Sponge	Rare (primary)
3	Moscovian - Asselian	Nansen	2nd order RST Slope to shelf-edge progradational	Mud mounds	200 – 900 m (0.5 to 6 km)	Phylloid algae *Palaeoaplysina*	Patchy (dolomite)
4	Moscovian - Asselian	Nansen Bel. Channel Tanquary	4th order TST-RST Carbonate shelf cycles	Patch reefs	15-20 m (50-100 m)	Phylloid algae *Palaeoaplysina*	Tight
5	Moscovian - Asselian	Nansen Bel. Channel Tanquary	4th order TST-RST Carbonate shelf cycles	Tabular banks	15-20 m (0.5 – 10 km)	Phylloid algae *Palaeoaplysina*	Tight
6	Asselian (Tolkien and Simpson reefs)	Mount Bayley, Tanquary, Nansen	3rd-4th order TST – RST restricted to open keep-up and progradational	Mud mounds to skeletal banks	50 – 200 m (200 – 500 m)	Bryozoan Sponge Phylloid algae Dasycladacean *Tubiphytes*	Excellent in flanks (vuggy dolomite)
7	Sakmarian	Raanes Great Bear Cape	2nd order TST keep-up shelf	Reef-mounds	60 – 130 m (200 – 500 m)	Bryozoan sponge	Tight
8	Artinskian - Kungurian	Great Bear Cape	3rd order RST shelf-edge progradational	Mud mounds	60 – 100 m (0.5 to 2 km)	Bryozoan Sponge	Tight

Table 1: Carboniferous and Permian reef categories, Sverdrup Basin

Figure 2. Early Permian Legolas reef (Ellesmere). Inclined flanks are dolomitized and porous

References

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