

Banff, Exshaw (Alberta Bakken) and Wabamun in Southern Alberta

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Summary

An estimated one to two billion dollars were invested in the Bakken equivalent Exshaw siltstone member of the Exshaw Formation in southern Alberta. Unfortunately this investment did not produce the fabulous returns obtained from the Bakken Formation in the Williston Basin, which is presently producing more than a million Barrels per day. The vertical “Alberta Bakken” type well 10-30-008-23W4 produced a quarter million barrels of oil from dolostone in the Stettler Formation, well below the Big Valley limestone and tight Exshaw siltstone. These porous dolostones only locally produce at economic rates in locations where they thicken up to at least 14 meters, as observed in the type well 10-30-008-23w4. Bakken exploration eventually led to the discovery of a new sandstone horizon in a transgressive-regressive cycle of the lower Banff Formation, which revived interest in the Exshaw to lower Banff succession.

Introduction

The stratigraphic interval comprising the Exshaw black-shale member, overlying Tournaisian Exshaw siltstone member, and Tournaisian black shale in the lower Banff Formation on the Rundle Shelf of southern Alberta (Richards et al., 1994) are commonly called the “Alberta Bakken” by the oil and gas industry, because that succession correlates with the tripartite lower Bakken shale member, middle Bakken siltstone and sandstone member and upper Bakken shale member of the Williston Basin, respectively. The Exshaw to lower Banff interval in southern Alberta and the Bakken in Williston Basin look similar in lithology and on gamma-ray logs. Drilling the middle Bakken of the Williston Basin has yielded fabulous returns with some horizontal wells producing over 1000 barrels a day. An estimated 1 to 2 billion dollars were hastily invested in the Alberta Bakken play. Unfortunately, reservoir characteristics of the calcareous to dolomitic Exshaw siltstone member of the “Alberta Bakken” differed substantially from the Bakken in the Williston Basin. Moreover, drill cuttings indicate that the vertical “Alberta Bakken” type well 10-30-008-23W4 produced oil from stained dolostones in the underlying Stettler Formation of the Wabamun Group instead of the Exshaw (Hartel et al., 2012). Zaitlin et al. (2011) introduced the term “Alberta Bakken petroleum system” and included the upper Stettler and Banff (e.g. Fig. 1) within it. Until 2011 there was only minor oil production from the Banff and that was predominantly from partially open fractures in tight, carbonaceous siltstone, argillaceous limestones and shales (e.g. Gatenby and Staniland, 2011).

Stratigraphy and correlation from Wabamun in the subsurface to Palliser in outcrop

Both the subsurface Famennian Wabamun and its coeval correlative the Palliser Formation in the Rockies comprise three main lithostratigraphic units (Table 1), that correlate as follows, in ascending order: 1) lower Stettler Formation of Wabamun with Morro Member in Palliser, 2) upper Stettler with lower Costigan Member in Palliser, and 3) Big Valley Formation with upper Costigan in Palliser. The lower Stettler comprises several informal members (Halbertsma, 1994) but a precise correlation between them and subdivisions in the Morro has not been established. The lower Wabamun/Palliser succession forms a vast carbonate ramp (> 400 km wide) comprising at least 4 lithofacies assemblages: 1) an eastern one (Saskatchewan) with restricted-marine to supratidal red beds, 2) an anhydrite-dominant belt (southern Alberta), 3) a dolomite dominated belt (west Alberta) and 4) a northwest belt (central Alberta into northeast British Columbia) with peritidal to relatively deep water limestone (Belyea, 1964). The lower Stettler of southern Alberta is dominated by restricted-marine anhydrite with subordinate dolostone which passes into laminated to burrow-mottled dolostone of the Morro (Meijer-Drees and Johnston, 1994). The lithologically similar and heterogeneous upper Stettler and lower Costigan of unit 2 include: horizontally-laminated to stromatolitic dolostone and limestone, fenestrate cryptalgal laminites, peloid-algal lime wackestone, intraclast breccia and solution-collapse breccia, silty dolostone, and peloid-skeletal packstone (Meijer-Drees et al., 1993; Richards et al., 2005). The third unit, the Big Valley and correlative upper Costigan, is dominated by argillaceous bioclastic lime wackestone to packstone (Richards et al., 2002, 2005).

SYSTEM	STAGE	UNIT	CENTRAL SOUTHERN ROCKY MTNS. ALTA., B.C.	SUBSURFACE SOUTHERN ALBERTA	WILLISTON BASIN
CARBONIFEROUS	TOURNAISIAN		Banff Limestone	Banff Limestone	Scallion Mbr.
			Banff Sandstone	Banff Sandstone	Lodgepole (part)
			lower Banff Shale	lower Banff Shale	upper Bakken
			Exshaw Silt	Exshaw Silt	middle Bakken
			Exshaw Shale	Exshaw Shale	lower Bakken
DEVONIAN	FAMENNIAN	3	upper Costigan	Big Valley	Big Valley
		2	lower Costigan	upper Stettler	Torquay / Three Forks
		1	Morro	lower Stettler	

Table 1. Schematic correlation of Upper Devonian to Lower Carboniferous formations in the Rocky Mountains, Alberta Basin and Williston Basin.

Thickness variations and contacts within the southern Alberta Wabamun

The Morro/lower Stettler unit constitutes most of the Wabamun-Palliser package. It thins eastwards from 600 m in the Rocky Mountains, through 200-300 m in south-central Alberta (Peterhansel and Pratt, 2008) to over 100 m of anhydrite with dolomite in southeast Alberta, to 40 m of siltstone, anhydrite and dolostone near the Saskatchewan border. In this lowest unit, the Stettler hosts the Crossfield field, which runs parallel to the 5th meridian near and south of Calgary. The lower Costigan/upper Stettler are a few 10s of meters thick in the Canadian Rockies and generally less than 15 m in the subsurface on the western cratonic platform, but present throughout the study area. In contrast, the Big Valley/upper Costigan unit is generally either a few meters thick or absent (Halbertsma, 1994; Richards et al., 1994; Johnston et al., 2010). Within the Stettler, dolostone obtains a cumulative thickness of up to 20 meters. In the type well at 10-30, 14 m of dolostone constitutes the reservoir as indicated by logs and cuttings (Hartel et al., 2012). In most wells, the regional porous upper Stettler dolostones are less than a few meters thick, which explains why those wells are subeconomic. At its type section in the Gulf Rumsey borehole at 06-30-033-21W4 near Big Valley Alberta, the Big Valley Formation is 13.6 m thick (Wonfor and Andrichuk, 1956). The unit attains a maximum thickness of about 30 m at a depocentre near its type section and in southwestern Saskatchewan. The formation occurs in most of the eastern part of the study area east of about range 20W4 but is generally less than 3 m thick and thickens eastwards. The Big Valley is absent near Olds because of non-deposition, loss of identity, or erosion (Wonfor and Andrichuk, 1956). Similarly, biostratigraphic work (Johnston et al., 2010) suggests that an erosional high existed at about the position of the Fifth Meridian in southwestern Alberta. Although there are from two to several meters of upper Costigan bioclastic limestone in the Bow Valley outcrops, the upper Costigan is absent from the Turtle Mountain to Crowsnest Lake outcrop belt of southwest Alberta.

It is not just the Big Valley/upper Costigan unit which is condensed in southwest Alberta but also the Exshaw-Banff interval. The entire section from the top of the Palliser to upper Banff is over 200 m at Jura Creek (Richards et al., 1994; 2005), but merely 20 m at Crowsnest Lake. Moreover, ten conodont zones, characteristic of the Morro to upper Banff and Pekisko, are observed in just 10 meters of section at Crowsnest Lake (Savoy and Harris, 1993). We suspect that depositional thinning resulted from deposition on the Montana highland of Douglas (1968). Furthermore, at Crowsnest Lake the organic Banff facies are much thicker than the 0.5 m of Exshaw shale (Richards et al., 2002), suggesting that the organic Banff shales, silts and sandstones are the main source rock and reservoir down south.

The Lower Stettler/Morro sequence reflects an east-west dipping ramp. The 2nd coeval unit of Upper Stettler and Lower Costigan features a relatively uniform restricted-marine dolomite-dominated facies, which can be observed over a distance of at least 200 km from east of Lethbridge, in core, to the

outcrop on Turtle Mountain. In the subsurface, the transgressive contact between units 1 (anhydritic lower Stettler) and 2 (upper Stettler dolostone) is gradational. In the mountains, however, the correlative boundary, between the subtidal Morro and overlying peritidal Costigan, is regressive and sharp at some locations (Meijer-Drees et al., 1993) but gradational at others. The observation that peritidal dolostones overly anhydrite in the east (subsurface) and neritic limestones of middle-ramp aspect in the eastern Front Ranges, indicates that westward shallowing took place over the eastern part of the former West Alberta Ridge during deposition of unit 2. The contact between units 2 and 3 is abrupt both in outcrop, where the upper Costigan erodes the lower Costigan (Meijer-Drees et al., 1993) and in the subsurface. On the Peace River Arch (Richards et al., 2002) and Montania near the US-Canada border, the Stettler-Big Valley unconformity shows bored ravinement surfaces (Fig. 2) over distances 800 km apart.

Similar to unit 2, the bioclastic limestones of the Big Valley and Upper Costigan formations of the 3rd correlative unit, also retain their facies over a large distance of over 300 km, from the type well 06-30-033-21w4 Rumsey to just below the type section of the Exshaw, at approximately 12-35-024-09w5 in Jura Creek. Where the Big Valley and upper Costigan are absent, the hiatus between the Wabamun/Palliser interval and overlying Exshaw is substantial and interpreted as largely of subaerial origin. The erosional pattern of unit 3 (Johnston et al., 2010) indicates that the western shallowing deduced from the facies relationships between units 1 and 2, culminated in further Late Devonian rejuvenation and easterly migration of the former late Middle to early Late Devonian Western Alberta Ridge.

The unconformity is overlain by at least 2 transgressive-regressive cycles of the Exshaw and lower Banff, which each start with dark and radioactive shale and gradually clean and coarsen upward into lighter siltstone, sandstone and carbonates. The calcareous to dolomitic siltstone of the Exshaw is finer grained and less porous than the middle Bakken (Sonnenberg and Pramudito, 2009) and it does not form a reservoir in the southwest. However, just north of the Town of Milk River, a newly discovered fine-grained sandstone unit that gradually overlies the lower Banff shale, forms a productive reservoir with locally 10 m of pay and 10% to 20% porosity. The sandstone underlies a crinoidal limestone resembling the productive Scallion Member of the Lodgepole in western Manitoba. A correlative succession of shale, sandstone and limestone in outcrop of the Crowsnest Pass region (Richards et al., 2002), closely resembles the lower Banff in core near the town of Milk River, hundreds of kilometers to the east.

Conclusions

Lithofacies in the Famennian Wabamun Group and their coeval correlatives in the Palliser Formation constitute a vast southwest-facing carbonate ramp comprising restricted-ramp and supratidal red beds in the east, a middle belt dominated by restricted-marine anhydrite with dolostone and a western belt of restricted- to middle- and distal-ramp carbonates. The ramp succession consists of three main divisions: 1) lower Stettler Formation with Morro Member, 2) upper Stettler with lower Costigan Member, and 3) Big Valley with upper Costigan. After a hiatus, recorded by granule lags and bored surfaces over paleo highs like the Peace River Arch and Montania, sedimentation resumed with deposition of the Big Valley and its coeval correlative the upper Costigan Member. Facies relationships and thickness variations suggest shallowing and subsequent erosion took place over a paleogeographic high, which possibly reflects rejuvenation and easterly migration of the West Alberta Ridge.

The Wabamun is overlain by the transgressive-regressive sequences in the Famennian to Tournaisian Exshaw and Tournaisian Banff, which both start with radioactive black shale and coarsen upward into siltstone, sandstone and carbonates. The calcareous-dolomitic siltstone of the Exshaw does not closely resemble the middle Bakken and does not contain economic hydrocarbon reservoirs in southwestern Alberta. Exploration of the “Alberta Bakken” eventually led to the discovery of a new productive sandstone horizon in the Lower Banff, near the town of Milk River, Alberta.

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Fig. 1. Eight small core fragments; from left to right: 2 porous Banff sandstones, 2 tightly cemented Exshaw siltstones, 3 porous Stettler stromatolitic dolostones of which 2 are obviously oil stained (tan) and one Stettler intraclast/collapse breccia (grey).



Fig. 2. Burrows in the top of the light-colored restricted-marine dolostone of the upper Stettler Formation immediately below the Big Valley limestone. The burrows are filled with coarse sand and granule size phosphatic bioclasts to a depth of 15 cm (Coin is 2.5 cm for scale).

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