The Bonnet Plume Basin, Yukon, Canada: A Previously Unrecognized Oil Play

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Summary

The Bonnet Plume Basin is a physiographic and structural depression near the eastern margin of the Frontal Belt of the Cordilleran Orogen in northeastern Yukon, Canada. It formed in early Late Cretaceous time by down-dropping Paleozoic strata along regional faults, and contains up to 7,500 m of clastic and carbonate sediments ranging from Precambrian to Tertiary in age. The oldest strata are Precambrian metasediments, which are unconformably overlain by a thick Paleozoic succession of marine mudstone and limestone. The Paleozoic sediments are unconformably overlain by the Bonnet Plume Formation, which is informally subdivided into a lower and upper unit. The lower Bonnet Plume Formation (Albian) consists of interbedded conglomerate, sandstone, mudstone and bituminous coal deposited in a marginal marine to fluvial environment, and the upper Bonnet Plume Formation (Maastrichtian to Paleocene) consists of fluvial sandstone, mudstone and lignite. Previous studies, based on regional geology, sediment type and stratigraphic thickness, concluded that the Bonnet Plume Basin has gas potential, but insignificant oil potential. However, these studies were not based on samples collected from within the basin. Two-hundred-twenty-eight samples collected from outcrop and drill core throughout the Bonnet Plume Basin were analyzed by Rock-Eval 6 programmed pyrolysis and combustion to assess the petroleum source rock potential of the strata. The results indicate the Bonnet Plume Formation is gas-prone and possibly oil-prone. Potential oil generation in the Bonnet Plume Formation is attributed to the occurrence of liptinite-bearing coal and previously unrecognized siliceous 'oil shale'. A hydrocarbon-rich tar associated with a naturally burning coal seam was also discovered in the upper Bonnet Plume Formation. Further work is planned to determine the quantity, thickness and geographic extent of oil-prone coal seams and carbonaceous mudstones throughout the basin.

Introduction

The Bonnet Plume Basin is one of eight oil and gas basins identified in the Yukon (Fig. 1). This basin has long been recognized for the occurrence of thick lignite coal seams (i.e., up to 17 m, Cameron and Beaton, 2000), including one that is naturally burning (de Sainville, 1898). In addition, Paleozoic strata are thought to be petroliferous, with ‘tar’ described as oozing from outcrops in several places (Camsell, 1906). Extensive coal exploration, including detailed geologic mapping, trenching and drilling, was undertaken in the late 1970’s to early 1980’s, resulting in the discovery of the largest coal resource in the Yukon: an estimated 2800 megatonnes (Cameron and Beaton, 2000). Link et al. (1989) reported total organic carbon values up to 9.6% (i.e., an excellent petroleum source rock) and Type I kerogen (i.e., oil-prone) and Type II kerogen (i.e., oil- and gas-prone) in Paleozoic strata from wells north of the basin. However, based on

regional geology, sediment type and stratigraphic thickness, Hannigan (2000) concluded that the Bonnet Plume Basin has gas potential, but insignificant oil potential. Specifically, lower Plaeozoic clastic and carbonate strata are thought to be potential source rocks, as are Cretaceous clastic strata (Hannigan, 2000). The median estimate for the total gas potential in the Bonnet Plume Basin is 896 Bcf of in-place gas, and the extensive coal deposits indicate that it has significant coalbed methane potential (Hannigan, 2000). Nevertheless, Hannigan's (2000) report is not based on samples collected from within the basin. The present study reports the results Rock-Eval 6 analyses of outcrop and drill core samples collected throughout the Bonnet Plume Basin in order to assess the petroleum source rock potential of the strata.

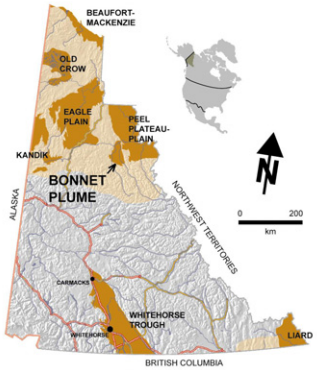

Figure 1: Petroleum basins in the Yukon.

Methods

Two-hundred-twenty-eight rock samples were collected from outcrop and drill core throughout the Bonnet Plume Basin. Source rock quantity, quality and thermal maturation level was determined by Rock-Eval 6 programmed pyrolysis and combustion using standard techniques by the Geological Survey of Canada in Calgary, Alberta. Technical details of the Rock-Eval apparatus, procedures and applications are available in Espitalie et al. (1985), Peters (1986), Peters and Casa (1994), Tyson (1995), Lafargue et al. (1998), Behar et al. (2001), and Fowler et al (2005), whereas a less technical summary is provided by Lowey and Long (2006).

Results

Selected Rock-Eval results, including hydrocarbons generated by pyrolitic degredation of kerogen and total organic carbon (i.e., S2 vs. TOC plots), and the hydrogen index and temperature of the maximum amount of hydrocarbons generated during pyrolitic degradation (i.e., HI vs. Tmax plots) are summarized in Figure 2.

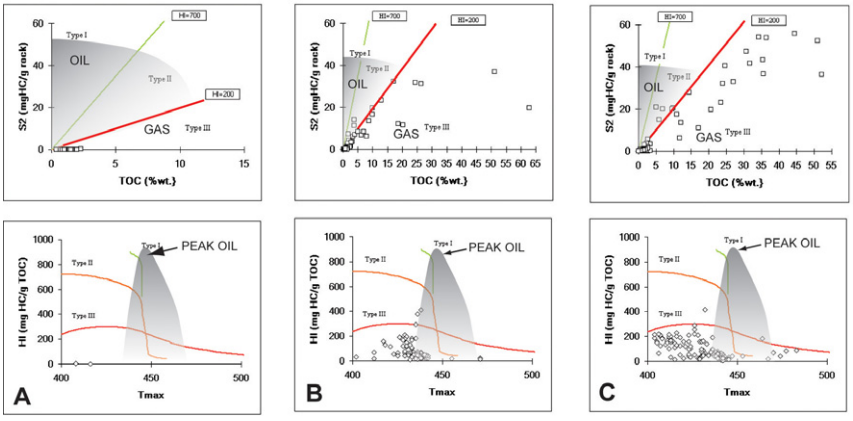

Figure 2: Rock-Eval results. A) Paleozoic strata; B) lower Bonnet Plume Formation; C) upper Bonnet Plume Formation.

Discussion and Conclusions

The Paleozoic strata contains small to moderate amounts of TOC, negligible to small amounts of S1 and small amounts of S2, indicating that overall, it is a poor source rock. HI values and the S2/S3 ratio suggest that only gas would be present. The T_{max} values are probably unreliable due to the low S2 values, and so the thermal maturity of the strata within the basin is uncertain. However, based on vitrinite reflectance and the conodont alteration index, Link and Bustin (1989) determined that Paleozoic strata north of the Bonnet Plume Basin is postmature and that thermal maturity increases southwards. In addition, Link et al. (1989) concluded that the Paleozoic strata currently has poor source rock potential, but probably generated oil in Devonian to Carboniferous time.

The lower Bonnet Plume Formation contains small to large amounts of TOC (note that coal defined as greater than 50 % by weight carbonaceous material), small to moderate amounts of S1 and small to large amounts of S2, indicating that overall, it is an excellent source rock. HI values, the S2/S3 ratio and the S2 vs. TOC and the HI vs. T_{max} plots suggest that gas and possibly oil are present. The presence of Type II kerogen (i.e., organic matter of marine origin that is oil- and gas-prone) is supported by the occurrence of dinoflagellate cysts (Nichols and Sweet, 1993), which indicate the lower Bonnet Plume Formation is in part marginal marine in origin. The T_{max} values indicate the rock is mainly thermally immature to early mature with respect to oil generation. According to Cameron and Beaton (2000), vitrinite reflectance values for the lower Bonnet Plume range from 0.55-0.65, whereas D.G.F. Long (written communication, January 22, 2002) states that the average vitrinite reflectance value is 0.47. In general, the vitrinite reflectance values agree with the maturation level determined by Rock-Eval analysis. Also, coal rank in the lower Bonnet Plume Formation is sub-bituminous A to high volatile C bituminous (Long, 1986; Cameron and Beaton, 2000), corresponding to the beginning half of the oil window (Fowler et al., 2005). Economic accumulations of petroleum are thought to occur if coal rank is less than or equal to high-volatile bituminous (Stack et al., 1982). In addition, oil generation is marginally supported by the composition of the coal, which contains up to 9.7 % liptinite (D.G.F. Long, written communication, January 22, 2002). According to Peters and Cassa (1994), 15-20 % liptinite is required for coal to generate oil.

The upper Bonnet Plume Formation contains small to large amounts of TOC, negligible to large amounts of S1 and negligible to large amounts of S2, indicating that overall, it is an excellent source rock. HI values, the S2/S3 ratio and the S2 vs. TOC and the HI vs. T_{max} plots suggest that gas and possibly oil are present. The T_{max} values indicate the rock is mainly thermally immature to early mature with respect to oil generation. According to D.G.F. Long (written communication, January 22, 2002), the average vitrinite reflectance values for the upper Bonnet Plume is 0.31**,** in general agreement with the maturation level determined by Rock-Eval analysis. Also, coal rank in the upper Bonnet Plume Formation is lignite (Cameron and Beaton, 2000), corresponding to pre-oil window conditions (Fowler et al., 2005). However, oil generation is supported by the composition of the lignite, which contains up to 19% liptinite (D.G.F. Long, written communication, January 22, 2002), and the previously unrecognized tar.

Potential oil generation in the Bonnet Plume Formation is attributed to the occurrence of liptinite-bearing coal and previously unrecognized oil shale. Numerous studies have shown that coal provides the source for commercial oil accumulations in numerous sedimentary basins (Hendrix et al., 1995, and references therein). Oil-prone coal is not only characterized by high HI and S2 values, but also high S1 values: i.e., it is thermally mature with respect to oil generation (Tissot and Welte, 1984). For example, sample W1-79 from the upper Bonnet Plume Formation displays characteristics similar to oil-prone coal with HI=203, S2=104.68 mg HC/g rock and S1=6.35 mg HC/g rock. Note that Peters (1986) cautions that Rock-Eval analysis tends to overestimate the liquid-hydrocarbon generative potential of coal. Several rock samples

from the Bonnet Plume Formation are also similar to 'siliceous' oil shale (i.e., clay minerals are predominant), rather than carbonate-rich oil shale (Duncan, 1976; Yen and Chilingar, 1976). Oil shale is characterized by high TOC and S2 values, but low S1 values: i.e., it is thermally immature with respect to oil generation (Hunt**,** 1996). For example, sample BP 79/17-201.2 from the lower Bonnet Plume Formation displays characteristics similar to oil shale with TOC=16.99 %, S2=32.28 mg HC/g rock, and S1=0.74 mg HC/g rock. In conclusion, the Bonnet Plume Formation is gas-prone and possibly oil-prone. Further work is planned to determine the quantity, thickness and geographic extent of oil-prone coal seams and carbonaceous mudstones throughout the basin.

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