An Organic Geochemical Investigation of the Paktoa C-60 Oil, Beaufort-Mackenzie Basin

Chunqing Jiang[1], Zhuoheng Chen[1], Dale Issler[1] and Kirk Osadetz[1,2]
[1]Natural Resources Canada, Geological Survey of Canada
[2]CMC Research Institutes Inc.

Introduction

An estimated 38 million m^3 (240 million barrels) of recoverable oil were discovered by Devon Energy in the Paktoa C-60 well in the Beaufort Sea during 2005-2006 (Anon., 2007; Callow, 2013). The petroleum discovered is a 20°API gravity and low sulfur (0.15%) crude oil in Tertiary Taglu Formation. A crude oil sample from drill stem testing number 4 (DST#4) over the depth interval of 1293-1311.5 m, referred to subsequently as the "Paktoa C-60 oil" has been subjected to extensive geochemical analysis to investigate its post-accumulation alteration, its source and thermal maturity level.

Method

Whole oil gas chromatography (GC) analysis was performed on the Paktoa C-60 oil sample to characterize its molecular compostion. Gas chromatography-mass spectrometry (GC-MS) analysis was peformed on the saturated and aromatic hydrocarbon fractions obtained from open column chromatographic separation of the oil to characterize and analyze its biomarker compositions. These compositional data are used to assess its post-accumulation alteration and to infer the depositional environment and thermal maturity level of potentail petroleum source rock intervals contributing to the Paktoa C-60 oil accumulation.

Results and Discussion

The geochemical composition of the Paktoa C-60 oil indicates severe alteration by biodegradation, probably anaerobically. GC trace of the sample is characterized by the total absence of common saturate hydrocarbon compounds, both the normal alkanes and the acyclic isoprenoids including pristane and phytane (Figure 1 top). The whole oil GC trace is dominated by an unresolved-complex-mixture (UCM) "hump" atop of which sit some distinct peaks/compounds identified as admantane and its C_1-C_2 alkylated derivatives, and C_{14}-C_{15}-C_{16} bicyclic sesquiterpanes (Figure 1 top). The Paktoa C-60 whole oil GC data suggests that the oil has experienced a significant degree of biodegradation indicated by the removal of all the acyclic saturated hydrocarbons that are usually the major recognizable components of a mature unaltered crude oil (Figure 1 bottom).

GC-MS and GC-MS/MS analyses of the saturated and aromatic hydrocarbon fractions demonstrate that regular steranes and C_{29} to C_{35} hopanes have been almost totally removed by microbial alteration, whereas the more biodegradation-resistant diasteranes, C_{27} Ts and Tm hopanes, and tricyclic terpanes appear to have been unaffected by biodegradation. In addition, 25-norhopanes, the biodegradation products of regular hopanes, occur in high abundance in the Paktoa C-60 oil. Other than triaromatic steranes, most other lower molecular weight polycyclic aromatic compounds including C_0-C_4 naphthalenes and C_0-C_2 phenanthrenes have been either totally or partially removed depending on their alkylation and isomer characteristics. The residual biomarker assemblage indicates that the Paktoa C-60 oil was subject to severe biodegradation (biodegradation Level 7 or higher, Peters and Moldowan, 1993, their Figure 3.62) after accumulation in the reservoir. Such extensive alteration by biodegradation is commonly observed in most of the heavy oil and oils sands from the Lloydminster and Athabasca regions. Despite the severe microbial alteration, gymnosperm plant derived biomarker isopimarane and norisopimarane are among the few distinct compounds distinguished from the UCM "hump", suggesting that these "source-specific" compounds are highly resistant to microbial alteration in the oil reservoir. Furthermore, the highly biodegradation-resistant biomarkers with an angiosperm source, such as the oleananes and bisnorlupanes that were reported previously in other biodegraded Tertiary oils from the Beaufort Sea (Curiale, 1991), and some of their aromatized derivatives also occur at high abundance in the Paktoa C-60 oil.

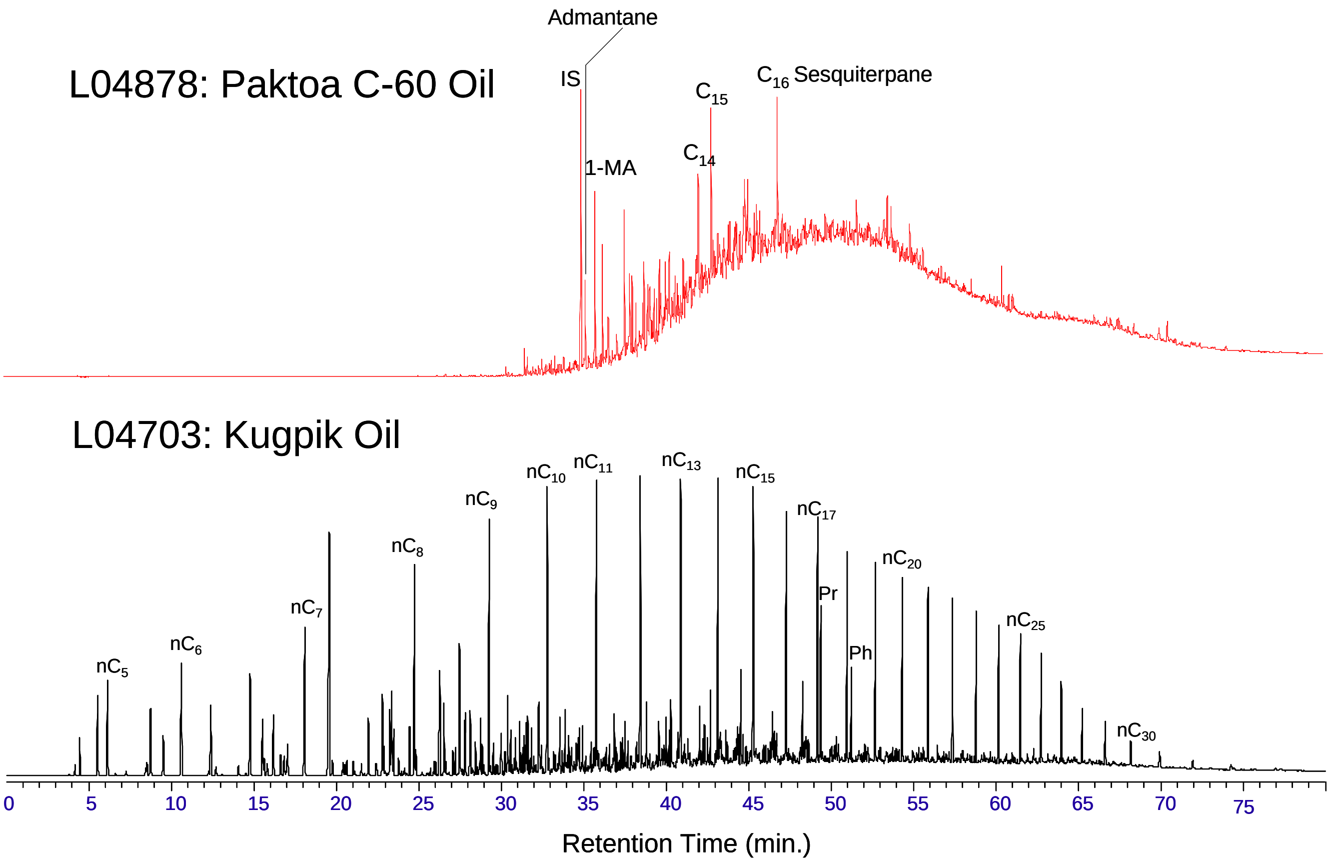

Figure 1. The composition of Paktoa C-60 DST#4 oil revealed by whole oil GC analysis (top) in comparison with a normal crude oil (bottom) from Beaufort-Mackenzie Basin. IS: Internal Standard Admantane-D16; 1-MA: 1-methyladmantane

Despite having been exposed to severe alteration, maturation and source information can still be inferred from the Paktoa C-60 oil based on the distribution of the biodegradation-resistant compounds. Using co-injection analysis of the oil with deuterated admantane as an internal standard, the content of admantanes in the Paktoa C-60 oil is estimated to be about 1.4%. Based on its extremely high concentration of diamondoids, 20^o API gravity, 0.1% pentane insoluble asphaltenes, and average molecular weight of 240 g/mole (the equivalent of nC_{17}), most of the Paktoa C-60 oil is believed to be a high maturity, high API gravity oil or condensate prior to the alteration by biodegradation. The maturity of the original oil and its source rock is estimated between 1.3-1.6% vitrinite reflectance from its distribution of methyl-admantane and methyl-dimantane isomers. This suggests that as much as 90% of the original oil accumulation, by volume, could have been "lost" as a result of its biodegradation. In comparison to the density of Lower Cretaceous Mannville Gp. oil sands and heavy oils in Western Canada Sedimentary

Basin (typically <10° API) the significantly lower Paktoa C-60 crude oil density (20° API) indicates the importance of crude oil composition on its physical characteristics subsequent to biodegradation. The characteristics and composition of the Paktoa C-60 oil is consistent with observations of biodegradation impacts on crude oil physical characteristics in low sulphur WCSB Colorado Gp. oils (Osadetz et al., 1994).

Natural gas in solution with the Paktoa C-60 oil has a dryness $C_1/(C_1\text{-}C_4)$ >99.2, consistent with a secondary biogenic origin related to anaerobic petroleum biodegradation (Larter et al., 2005). The Paktoa C-60 oil lacks a significant associated gas accumulation and has a low gas-to-oil ratio of 19.7. This indicates that an immense volume of secondary biogenic gas that was generated during the anaerobic oil biodegradation has been mostly lost into the marine and atmospheric sinks by leakage. Mud gas analysis during drilling indicated that mud gas was much drier at depths <1500m than mud gas >1500m, also consistent with a secondary biogenic origin due to oil biodegradation. Diagnostic gas carbon isotope data are, unfortunately, not available.

The oleananes, bisnorlupanes and tricyclic diterpanes in the Paktoa C-60 oil are currently known only to occur in Beaufort-Mackenzie Basin Tertiary source rocks (Snowdon, et al, 2004; Li et al, 2008, 2010). Therefore the abundant occurrence of these higher plant biomarkers in the Paktoa C-60 oil indicates a source in the Tertiary deltaic sequences in which the oil has also accumulated. A mixed thermal maturity signature indicated, for example, by the mixture of diamondoids (a high maturity indicator) and abundant oleananes and bisnorlupanes (a low maturity indicator) suggests that prior to alteration the Paktoa oil was sourced primarily from a deep seated source rock at late-oil-generation to early gas-generation stage with minor contributions from other, shallower Tertiary source rocks. The upward migration of the high maturity light oil may have co-mingled with low maturity oils while migrating upward through the Tertiary successions (e.g. Taglu, Aklak) on the way to accumulation in the Paktoa C-60 structure.

The volumetrically dominant oil component from deeper source rocks likely originates in the Upper Cretaceous succession, based on the observed non-altered diasteranes distribution. The Paktoa C-60 oil has a diasterane C_{27}/C_{29} ratio ~40%. This is similar to crude oils in the Tarsiut, Nipterk and Pitsiulak accumulations that are inferred derived from Upper Cretaceous source rocks (Li et al, 2010). Typically Beaufort Mackenzie Basin oils with source rocks in the Tertiary succession have a diasterane C_{27}/C_{29} ratio <25% (ibid.). Current geological and geophysical models also support Beaufort Mackenzie Basin petroleum systems with high thermal maturities originating from Upper Cretaceous source rocks.

Conclusions

- The Paktoa C-60 oil is a mixture of two crude oils of high quality and low sulfur content. The predominant contribution is from high thermal maturity crude oil or gas condensate derived from underlying high thermal maturity source rocks in the Upper Cretaceous succession. A secondary, subordinate contribution is from crude oil, containing distinctive biological markers indicative of lower thermal maturity oils derived from the overlying Tertiary succession in which the accumulation occurs.
- The current Paktoa C-60 crude oil and solution natural gas exhibit compositional characteristics indicating an alteration of the accumulated high quality crude oil by extreme anaerobic biodegradation. Based on the selective and sequential biodegradation of crude oil molecular compounds, the Paktoa C-60 oil seems more extensively biodegraded than Athabasca oil sands and Lloydminster heavy oils. As much as 90% of the original accumulated oil volume may have been “lost” as a result of microbial consumption.
- Most of an immense volume of the secondary biogenic gas generated as a consequence of the anaerobic crude oil alteration was “lost” into the overlying oceanic and atmospheric sinks.

- In comparison to Lower Cretaceous Mannville Gp. oil sands and heavy oils (typically <10^o API) the lower density of the Paktoa C-60 crude oil, 20^o API, indicates the importance of crude oil composition, especially the role of sulfur, on crude oil physical characteristics subsequent to biodegradation.

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