geoconvention
Calgary • Canada • May 15-17 2023

Oil-Oil and Oil-Source Correlation and the Origin of the Heavy Oil and Bitumen Accumulations of North Eastern Alberta, Canada

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Summary

The saturated and aromatic hydrocarbon composition of source rock samples from the Duvernay, Exshaw, Lower Banff, Whistler member, Doig, Nordegg, Gordondale and Poker Chip shales was investigated by gas chromatography–mass spectrometry (GC–MS). The study also included produced oils from the Clearwater Play at Marten Hills and Peace River oil sands; reservoir cores from Athabasca and Cold Lake oil sands and Grosmont bitumen. Due to severe biodegradation in the Grosmont bitumen, oil-oil and oil-source correlation using traditional biomarkers proved to be challenging. Therefore, aromatic steroid hydrocarbons which display strong resistance to biodegradation, were investigated for oil-oil and oil-source correlation, since these compounds are present in all sample material analysed.

The aromatic steroid hydrocarbon distributions reveal compositional features that are able to distinguish Paleozoic versus Mesozoic sources. The Duvernay, Exshaw and Lower Banff formation extracts lack triaromatic-dimethylcholesteroids (TA-DMC) and triaromatic dinosteroids. Conversely, the Nordegg, Gordondale and Poker Chip shale extracts contain appreciable quantities of TA-DMC's and triaromatic dinosteroids. Meanwhile, the Doig extract displayed compositions falling between the Jurassic and Paleozoic source types. The TA-DMC's and triaromatic dinosteroids are abundant components in the Clearwater, Peace River, Athabasca, Cold Lake and Grosmont samples supporting a strong Jurassic source contribution.

Introduction

The origin (source rocks) and timing of petroleum emplacement in the Albertan oil sands region is the subject of considerable debate. Among many hypotheses, the most widely accepted involves multiple source rocks (e.g., Creaney et al., 1994). Some organic geochemical studies (e.g., Fowler et al., 2001) propose the Upper Devonian–Lower Mississippian Exshaw Formation as the main source of petroleum in Alberta. In contrast, four-dimensional basin modeling and inorganic petroleum fingerprinting suggest the dominant source rock is the Jurassic Gordondale Member (Higley et al., 2009; Berbesi et al., 2012; Finlay et al., 2012). The previous studies have been hampered by the lack of access to appropriate source rock samples, especially the Exshaw Formation.

Severe biodegradation may complicate biomarker interpretations in the Athabasca oil sands and Grosmont bitumen, and in extreme cases steranes, diasteranes, hopanes and tricyclic terpanes may be completely destroyed (Figure 1). Therefore, to identify contributions to the oil sands from the potential source rock units including Duvernay, Exshaw, Lower Banff, Doig, Nordegg,

Gordondale (Asgar-Deen et al., 2004) and Poker Chip shales, we propose the application of the biodegradation resistant aromatic steroid hydrocarbons (Bennett and Jiang, 2021).

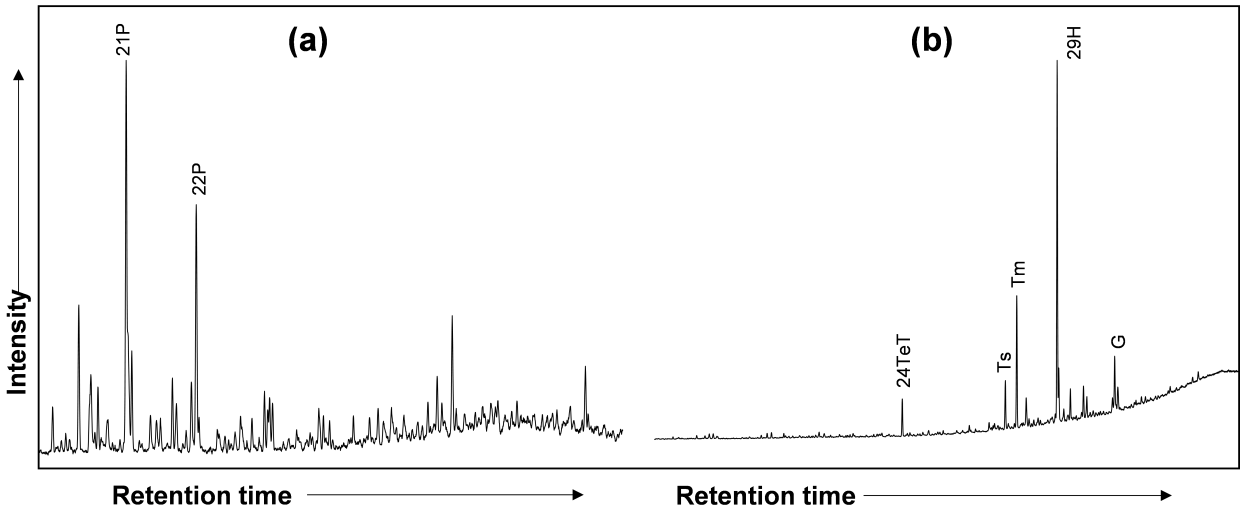

Figure 1. Partial reconstructed (a) m/z 217 and (b) 191 mass chromatograms representing sterane and terpane distributions respectively in Grosmont bitumen (369.2 m; well 06-08-094-21W4). Key: 21P = C_{21} pregnane, 29H = C_{29} hopane, 24TeT = C_{24} tetracyclic terpane, G = gammacerane.

Method

The source rocks, oil sands and carbonate core samples were crushed prior to Soxhlet extraction using dichloromethane (DCM) to recover the total soluble extracts (TSE). The total hydrocarbon (THC) fraction was isolated from TSEs and oils by solid phase extraction (SPE) on a polar sorbent phase. The THC fraction was separated into the saturated and aromatic hydrocarbon fractions using a modified silica gel pipette method described in Bastow et al. (2007). The saturated and aromatic hydrocarbon fractions were analysed by GC-MS. Internal standards were added for quantification purposes.

Results and Discussion

The methyltriaromatic steroid hydrocarbons are monitored by the m/z 245 mass chromatogram as shown in Figure 2 for the Duvernay, Exshaw, Gordondale and Poker Chip shales. The methyltriaromatic steroid hydrocarbon compositions encountered in the Duvernay and Exshaw formation samples are characterized by relatively simple distributions dominated by the 2-, 3- and 4-methyltriaromatic steroid hydrocarbon species and an apparent lack or low contributions of the dinosteroid (DA-DF) derived components (Figure 2). In contrast, the methyltriaromatic steroid composition of the Gordondale and Poker Chip shale source rocks display more complex distributions characterized by abundant 2-, 3-, 4-methyltriaromatic steroids as well as the dinosteroid derived molecular markers (DA-DF). The compositional features shown in Figure 2 afford recognition of Jurassic versus Devonian – Mississippian source rocks in the Western Canada Sedimentary Basin.

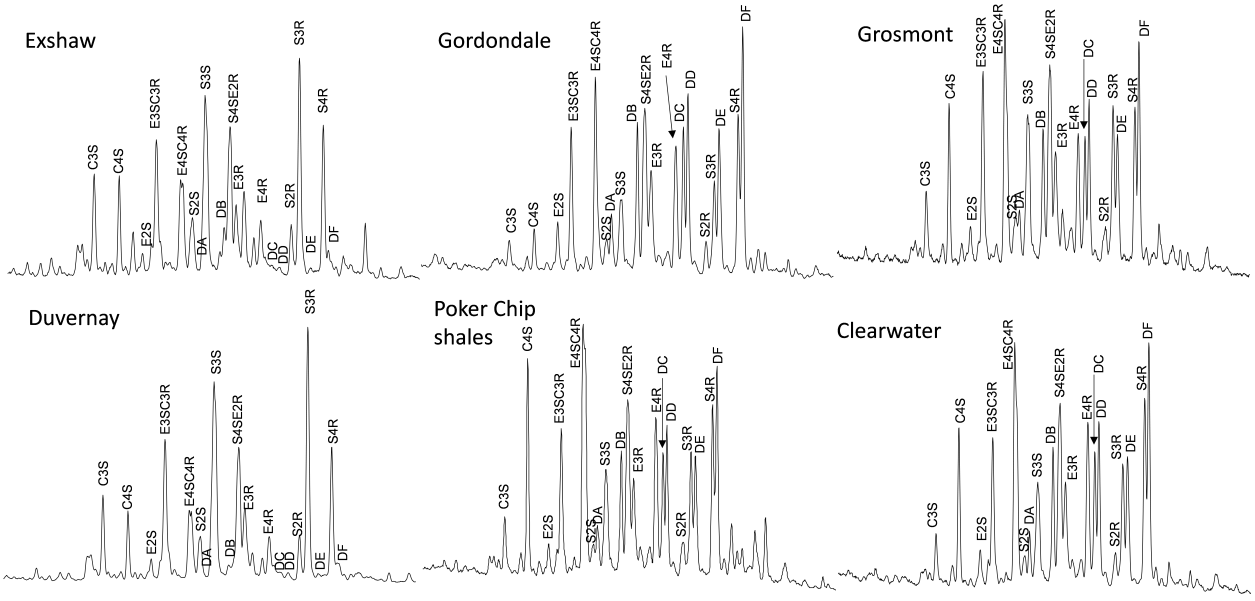

Figure 2. Partial reconstructed m/z 245 mass chromatograms representing methyltriaromatic steroid hydrocarbons in the studied samples. Key: C3S = 3-methyltriaromatic cholesteroid 20S, E2S = 2-methyltriaromatic ergosteroid 20S, S4R = 4-methyltriaromatic stigmasteroid 20R, DA-DF = triaromatic dinosteroids.

The m/z 245 mass chromatograms of methyltriaromatic steroid hydrocarbons in samples from the Clearwater play (least biodegraded; *n*-alkanes present) and Grosmont bitumen (most biodegraded – diasteranes degraded) are shown in Figure 2. The aromatic steroid hydrocarbons are highly resistant to biodegradation and have retained the original source rock compositional features, even in the severely biodegraded Grosmont bitumen. The methyltriaromatic steroid composition of the Grosmont bitumen closely resembles those of the Gordondale / Poker Chip shale suggesting a strong Jurassic source contribution to the Grosmont bitumen. Interestingly, although not shown here, the presence of abundant triaromatic dinosteroids (DA-DF) and their distributions is consistent amongst samples representing Marten Hills, Peace River, Cold Lake, Athabasca and Grosmont bitumen suggesting a similar genetic origin for the accumulations.

The methyltriaromatic steroid hydrocarbons form one part of this study which also included investigation of the steranes, hopanes, triaromatic steroid hydrocarbons and aromatic-8,14-secohopanes which provide key information for identifying the compositional features associated with the candidate source rocks. For example, the presence of TA-DMC amongst the regular triaromatic steroid hydrocarbon distributions represent key characteristics of the Gordondale and Poker Chip shale extracts. The TA-DMC are thought to derive from dinoflagellates, haptophytes and diatoms and provide a useful parameter to distinguish Paleozoic from Mesozoic and Younger oils and rock extracts (Barbanti et al., 2011). The Exshaw and Duvernay source rock extracts show almost complete lack of these components, again providing additional biomarker evidence to enable source recognition. In addition, Poker Chip shales contain C_{28} bisnorhopane, providing a potential Jurassic source for the molecular marker also encountered in the Oil sands and Grosmont bitumen. Furthermore, isotopic data based on sulfur and nitrogen stable isotopes may provide additional evidence for the source contributions to the oil sands accumulations.

Conclusions

The presence of TA-DMC and triaromatic dinosteroids has been recognized in samples representing the Clearwater play, Peace River, Cold Lake, Athabasca and Grosmont bitumen. The TA-DMC and triaromatic dinosteroids are encountered in the Jurassic source rocks, while they are lacking in the Devonian-Mississippian source rocks thereby providing molecular indictors for the presence of a significant Jurassic contribution to the oil sands and Grosmont bitumen. The presence of C_{28} bisnorhopane and appreciable quantities of diasteranes in extracts from the Poker Chip shale suggests these components may originate from a Jurassic source.

Acknowledgements

We thank the Energy and Resources Conservation Board (now the Alberta Energy Regulator) for access to core samples. Dean Rokosh is thanked for providing sample material for the study. We also acknowledge the support from the Geological Survey of Canada's Geoscience for New Energy Supply (GNES) research program.

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