Chemometrics application in assessing heavy oil reservoir fluid heterogeneity in Southeastern Mexican heavy oil fields

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Summary

Chemometrics method was used in tandem with Gas Chromatography-Mass Spectrometry (GC-MS) and Fourier Transform Ion Cyclotron Resonance-Mass Spectrometry (FTICR-MS) to characterize geochemical composition variations of 47 heavy to extra-heavy oil samples and to estimate fluid heterogeneity in heavy oil reservoirs in Southeastern Mexico. Three broad types of organic sources (marine carbonate, hypersaline and deltaic marine) with slightly different maturity levels, various biodegradation scales and interactions between oil biodegradation and mixing were identified based on GC-MS and FTICR-MS data. Principal component analysis (PCA) of compositional parameters suggested heavy oil composition variations were predominantly controlled by organic source and significantly affected by biodegradation levels within each genetic group. Effective oil compositional parameters for organic sources, variable biodegradation and mixing levels were determined by PCA, which classified four oil families: light biodegradation, severe biodegradation, ongoing biodegradation and mixing (biodegraded + fresh charged). Geochemical determination of fluid heterogeneity within the heterogenous geophysical reservoir framework supports the comprehensive characterization of heavy oil reservoir compartmentalization.

Theory / Method / Workflow

Thorough characterizations of fluid heterogeneity in heavy oil reservoirs is essential for recovery method optimization, well placement design and field management. Biodegradation is the predominant geological control of heavy oil fluid heterogeneity (Gates et al., 2008). Biodegradation consumes a wide variety of heteroatom compounds while accumulating highly refractory compound species and biomass constituent compounds, unveiled by FTICR-MS data (Oldenburg et al., 2017). Significant proportions of resins + asphaltenes of the samples in this study (33.99–48.73%) suggested by SARA (saturated hydrocarbon, aromatic hydrocarbon, resins and asphaltenes) analysis results necessitated geochemical fingerprinting of both fractions by FTICR-MS in illuminating petroleum origin and alterations, apart from the routine of analyzing oil hydrocarbon species by GC-MS (Oldenburg et al., 2014). Principal Component Analysis (PCA) excels at processing numerous correlated parameters and large sample sets simultaneously (Christensen et al., 2005) and was adopted to interpret the complicated generation and alteration history of the heavy oils.

Results, Observations, Conclusions

Hydrocarbon compound distributions resolved by GC-MS revealed tricyclic–tetracyclic terpane, hopane and sterane parameters as efficient indicators for identifying a marine carbonate source, a hypersaline source and a deltaic marine source respectively for the oils. Various biodegradation influences were reflected in different consumption rates of 2–4 ring aromatic hydrocarbons, significant accumulation of naphthenic acids and O2S compound species, O2_3/O2_2 ratio (ion

intensity ratio of double bond equivalent (DBE) 3 group over DBE 2 group of the O2 class), N_10/N_9 ratio (ion intensity ratio of DBE 10 group over DBE 9 group of the nitrogen class) and S•_7/ S•_6 ratio (ion intensity ratio of DBE 7 group over DBE 6 group of the sulfur radical ion class). Occurrence of *n*-alkanes, acyclic alkanes and naphthalene either reflected low degrees of biodegradation or was introduced by fresh oil charge mixed with severely biodegraded oils. PCA of efficient compositional parameters suggested organic sources primarily divided oils in genetic groups while biodegradation predominated in causing oil composition variations within each genetic group. PCA results showed that DBE 1 group intensity of the O2 class was related to organic sources while ion intensities of DBE 3 to 6 and 8 groups of the O2 class were controlled by various biodegradation scales. Small differences in maturity level were indicated in different organic sources by great affinities between oil genetic parameters and maturity parameters, which included normalized total hydrocarbon ion (both radical and protonated ions) intensity (HC total, %) and normalized sulfur radical ion intensity (S radical, %) relative to total ion intensity of each sample and average molecular mass of protonated hydrocarbon species (HC_AMM, %) (Fig. 1A). According to the PCA results, cross plot of summed ion intensity of DBE groups 3 to 6 and 8 of the O2 class vs. summed concentration of *n*-alkanes, acyclic alkanes and naphthalene were proposed to cluster oil samples into four families: light biodegradation, severe biodegradation, ongoing biodegradation and mixing (Fig. 1B). Geochemical characterizations of fluid heterogeneity combined with geophysical data descriptive of heavy oil reservoir heterogeneity enabled comprehensive estimations of reservoir heterogeneity in the study area.

Novel/Additive Information

The combination of FTICR-MS and GC-MS data sets extended the geochemical delineation scope of conventional oils by GC-MS data only and provided comprehensive mapping of heavy oil fluid heterogeneity. The application of PCA with a complete geochemical fingerprinting dataset of both FTICR-MS and GC-MS enabled identifications of effective geochemical compositional proxies for various geological factors controlling heavy oil fluid heterogeneity and grouping of heavy oils.

Acknowledgements

References

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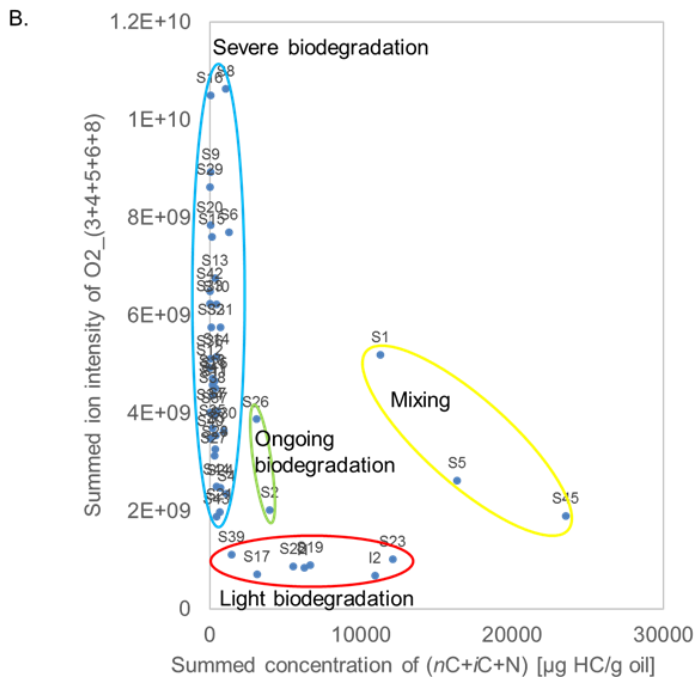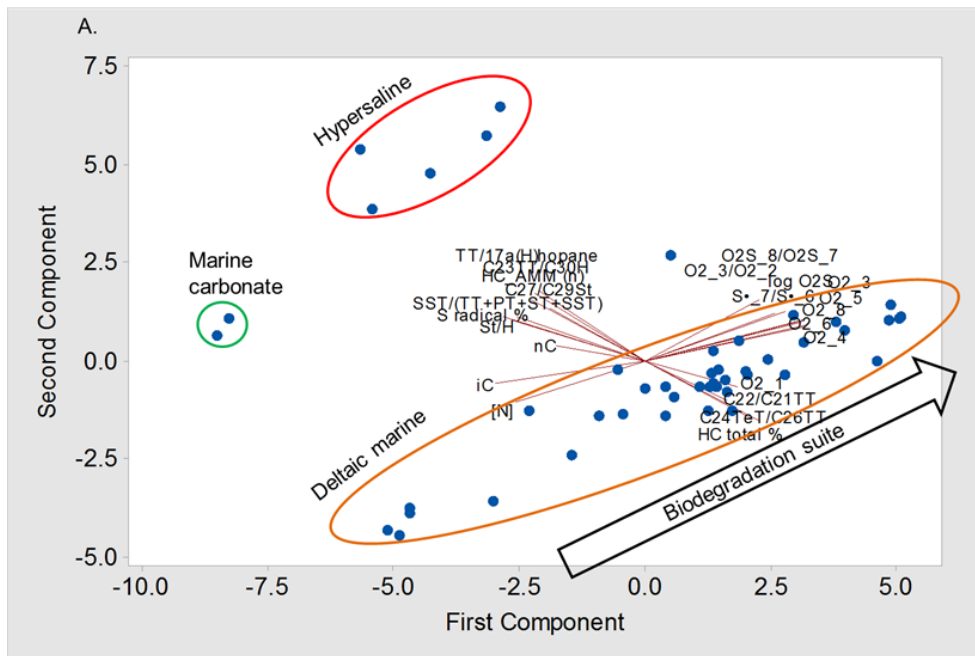
Figure 1. (A) Biplot generated by PCA of effective geochemical composition parameters of heavy oils; (B) Oil grouping results by cross plot of summed ion intensity of DBE groups 3 to 6 and 8 of O2 class vs. summed concentration of n-alkanes (nC), acyclic alkanes (iC) and naphthalene ([nC+iC+N], µg HC/g oil). Note: ongoing biodegradation refers to biodegradation of both fresh charged oil and the previously in-reservoir biodegraded oil; mixing refers to biodegraded oil mixed with fresh charges.