Source and Petroleum Generation Potential of Jordanian Oil- Shale

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Abstract

In Middle East countries exploration for unconventional resources (e.g. tight gas and oil as well as oil shale) is of relatively low priority because many of them have large conventional oil reserves. Recently, however, global energy providers and governments have been investing in unconventional oil sources. One promising example is in Jordan, where many occurrences of oil shale are accessible (up to 1000 meters depth) to In situ Conversion Process (ICP) technologies. In this study, high-resolution molecular proxies as well as bulk geochemical records from three cores in two sub-basins of Eocene organic-rich marls (known as “oil shale”) from central Jordan are presented to show the variability in organic matter (OM) quality and composition, and assess their hydrocarbon (HC) generation potential and maturity with emphasis on the occurrence of sulfur (S) in the form of organo-sulfur compounds.

The bulk geochemical records show high amplitude, high frequency variations in total organic carbon (TOC, min <1 %, max 37%, av ~10 %) and an excellent correlation with total S (TS, R2 = 0.96). Combined with high yields of bitumen and Rock Eval Hydrogen Index (HI) values between 500 and 900 mg HC/g TOC, this confirms the presence of hydrogen rich kerogen with excellent petroleum potential. Low abundances of pyrite and highly diverse mixtures of organo-sulfur compounds (including alkylated thiolanes, thiophenes, benzothiophenes etc.) identified using 2D GC-MS and Pyrolysis-2D GC-MS emphasize the dominance of S-bound OM. The presence of S-rich Type II kerogen in these rocks has major implications for the temperature and timing of H2S and HC generation, since cracking of relatively weak S-S and C-S bonds abundant in Type IIs kerogens occurs at significantly lower temperatures compared to the cracking of C-C bonds that dominate in lower sulfur kerogens.

Bulk geochemical and lipid biomarker data (e.g. *n*-alkanes, isoprenoids, steranes) support a primary marine algal phytoplankton source likely related to enhanced primary productivity, with minor but variable contributions of terrestrial OM (including leaf wax lipids). The dominance of amorphous organic matter points towards intense microbiological alteration of marine/algal OM, supported by abundant and diverse hopane biomarkers. 4-methylsteranes, high sterane/hopane ratios, and high abundance and of C27 steranes further support a variable but overall algal/bacterial OM source, likely related to enhanced phytoplankton primary productivity.

Despite the short distance between study sites (e.g. approx. 15 km between two cores from within the same sub-basin), similar lithostratigraphic units and very similar bulk geochemical characteristics (e.g. same pronounced TOC variability with relatively constant HI indicating a largely uniform source of OM), the bitumen content (up to 294 mg/g TOC; average 160 mg/g TOC) and composition differs

substantially in the samples between the three study sites and at the vertical (sub-m) scale, with pronounced fluctuations in non-flowable hetero-atomic polar compounds (av. 67%, 38% and 44% in the three cores, respectively) and very low proportions of saturated HCs (< 1 %). In addition to input variations, these differences in the amounts and bulk compositions of the bitumen fractions are likely caused by different burial depths, with two of the study sites being located in a shallow, possibly enclosed sub-basin on the inner shelf compared to a deeper shelf setting with significantly larger burial depths of the third site. Overall, the high solvent soluble extract yields in all study cores suggest that commercially interesting amounts of HCs could be generated, but the high polar compound contents will impact the flow properties.

The results of 31 sets of molecular maturity parameters (saturated and aromatic hydrocarbon ratios) in combination with statistical principal component analysis (PCA) indicate that there are different apparent maturity levels between the lithological units within the same study core, with the maturity parameter values also varying significantly between the two sub-basins studied. Variations in apparent maturity levels from the two cores in the same basin with small burial depths, suggest effects of host- rock lithology and/or the influence of preservation state of the labile, hydrogen-rich OM, rather than conventional geothermal gradient effects. The PCA results emphasize the limitations of using individual maturity parameters and carries important implications for the assessment of thermal maturity levels and therefore for prospect/play risking.

The immature and internally heterogeneous marls from Jordan provide new information on how OM may behave from sub-m to basin scales, and the results from this study will contribute to models for unconventional resource play assessment with impact beyond Jordan.