Shale oil enrichment: Insights from combined organic geochemical, petrophysical and petrographical observations

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Shale oil produced directly from source rock reservoirs represents a valuable global energy resource. In this contribution data from lacustrine and marine source rocks of the Songliao and Junggar basins (China) and the Central Graben (Norwegian North Sea), as well as coals from the Ukrainian Donbas are presented to illustrate how both primary depositional and thermal maturation-related processes may affect the physical properties of the accumulated oil, as well as the storage and expulsion behaviour of the source rock. Shale oil accumulation in the lacustrine Lucaogou Formation of the Junggar Basin is characterized to a large degree by a complex reservoir architecture, leading to different accumulation mechanisms in the lower and upper members of the prolific source formation. Both members contain sand layers that may act as drainage layers for expulsed oil. Oil-source-correlation proves that in the lower member the oil accumulated in sandstone interlayers is sourced from the directly adjacent source rock, and density and viscosity are mainly controlled by the primary depositional setting (e.g., salinity variations and resulting change in primary bioproductivity) and source rock thermal maturity, as well as minor fractionation during expulsion. In contrast, in the upper member, secondary migration over longer distances into sandstone interlayers and resulting hydrocarbon fractionation and mixing are more important controlling factors for oil property distributions. In general, the expelled shale oil shows the highest density and viscosity at peak oil maturity of the source rock, as evidenced both from production data and from hydrous pyrolysis experiments conducted on the Locaogou Formation. The same characteristics could experimentally be proven for the lacustrine Qingshankou Formation in the Songliao Basin, where the amount of high-molecular weight bitumen (soluble part of the S2 peak from Rock-Eval pyrolysis) peaks together with both the amount of free hydrocarbons indicated by the Rock-Eval S1 peak, the total extractable organic matter, as well as the corresponding saturated vs. aromatic compound ratios. This interpreted maximum of shale oil in place at ~0.8 %Rr (oil peak) is followed by a sharp decline in all of the aforementioned parameters at slightly higher thermal maturity (0.9 %Rr). This may indicate the onset of hydrocarbon expulsion at > 0.8 %Rr, as well as a relatively good expulsion efficiency as observed also for the Lucaogou Formation in pyrolysis experiments. The moment of expulsion can also be traced by combined gas adsorption and scanning electron microscopy which indicates pore occlusion by pre-oil solid bitumen at the oil peak, and gradual opening of pores due to expulsion at advancing maturity. The gas storage and retention behaviour of the investigated shales may hence abruptly change with ongoing thermal maturation, as matrix pores are liberated from occluding hydrocarbons. Pore occlusion and changing physisorption capacity in response to the presence and molecular composition of in-situ solid bitumen is also visible in scanning electron microscopy and gas adsorption data from the terrestrially influenced, marine source rocks of the Mandal Formation in the Central Graben of the Norwegian North Sea, as well as similar pore structural results obtained from bituminous coals from the Ukrainian Donbas. The presented results highlight the complex enrichment and expulsion processes associated with shale oilplays.