EAGLE FORD SHALE – A NATURAL LABORATORY TO STUDY THE EFFECTS OF THERMAL MATURITY, OIL CRACKING AND PRIMARY EXPULSION

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Introduction

The Eagle Ford Shale is a major unconventional liquids/condensate play in southern Texas (USA). Long known as the source of oils produced in adjacent reservoirs above (Olmos and Austin Chalk) and below (Buda and Edwards limestone), the Eagle Ford itself was not considered a resource until 2008 when the use of horizontal drilling and hydraulic fracturing showed that the low permeability formation could be productive.

Lower Eagle Ford source sedimentation occurred during the major marine transgression of the Cenomanian-Turonian OAE2, resulting in the anoxic deposition of an extensive laterally continuous organic-rich (~1-6% TOC) marl dominated by Type II kerogen. The formation spans the entire range of thermal maturity following a northwest-southeast trend from immature outcrops in central Texas into the dry gas window as it dips towards the Gulf. Liquids production occurs between ~1.2 and 4.3 km depth.

In this study, fifty-eight oils/condensates produced from Eagle Ford Shale (2.16 to 4.29 km TVD) were extensively characterized. The oils ranged from 29.8 to 77.5 °API, 0.0 to 1.43 wt%S, 0.0 to 0.17 wt%N, and 34.2 to 93.9 %C_{15+} saturates. The Eagle Ford petroleum system is a natural laboratory ideal to study the effects of thermal maturation, oil cracking, and primary expulsion as variability due to source facies is minimal and there is no secondary alterations due to phase behaviour, migration, biodegradation or TSR.

Results

Hydrocarbon distributions (e.g., *n*-alkanes, isoprenoids, biomarkers) and their $\delta^{13}C$ values indicate that the organic facies of the Eagle Ford Shale is mostly homogeneous throughout the main play. The source kerogen is inferred to be typical of Type II marine marls deposited under anoxic/euxinic, conditions. The source facies east of the San Marcos Arch received a higher input of terrestrial organic matter and higher clay content.

Nearly all variance in composition within the sample suite can be attributed to differences in the level of thermal maturity (generation and cracking). Two trends emerge when maturity-dependent parameters are plotted as a function of true vertical depth (Fig. 1). Oils updip of the Edwards Shelf edge show a linear correlation with °API gravity, a progressive decrease in cyclic biomarkers, and only a slight increase in adamantanes in the deepest samples. Oils downdip of the shelf edge and mostly within the Karnes Trough, also show a linear correlation with °API gravity, saturated biomarkers occur in low concentrations or below limits of detection, and adamantanes increase with depth. The two trends are offset by ~0.6 km, which is approximately the equal to the vertical displacement of the Karnes Trough graben.

This Eagle Ford sample suite provides a test bed to verify the accuracy maturity indicators. Most molecular parameters based on saturated and aromatic hydrocarbon relative abundance, isomeric distributions, or $\delta^{13}C$ generally agree well with published trends. A few parameters, such as the MDI (methyl diamantine index), are less correlative than expected. Biomarkers are most abundant in the lowest maturity oils (~0.6 $\%R_o$) and decrease to trace amounts within the oil window (~1.0 $\%R_o$). Hydrocarbon cracking starts within the oil window (~1.0 $\%R_o$) but becomes significant at higher levels of thermal stress (~1.3 $\%R_o$). At a given level of source rock maturity, petroleum produced from the Eagle Ford appears to be more mature then the inferred source for conventional oils. This is explained as the unconventional fluids reflect the instantaneous composition of the formation's current maturity while fluids in conventional reservoirs are composites of cumulative generation as fluid is continually expelled and migrated from the source. This model is consistent with regional trends in the gas-to-oil ratio.

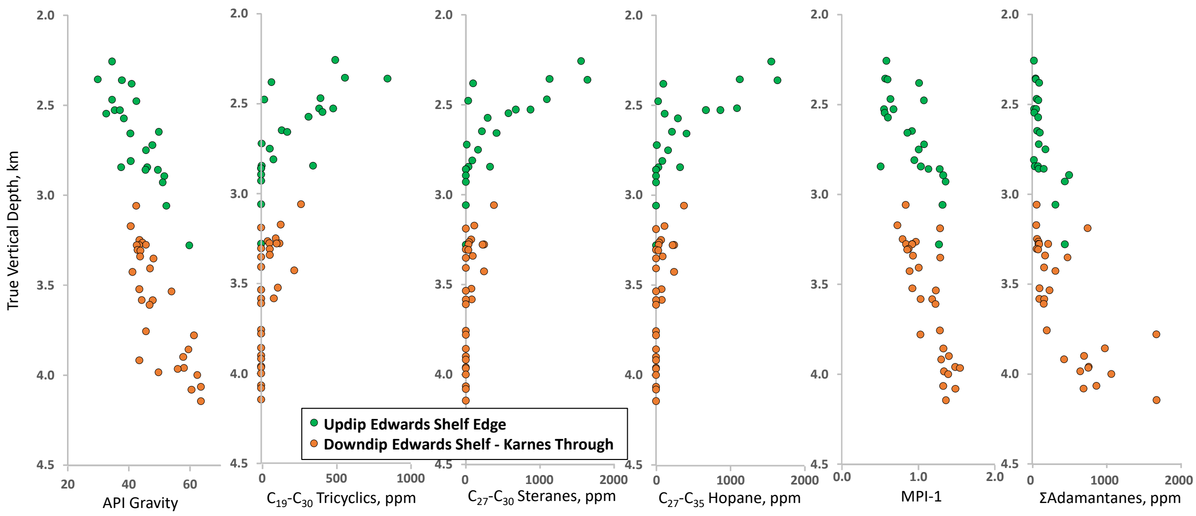

Figure 1. *Maturity-dependent parameters versus TVD. Two regional trends defined by the Cretaceous shelf edge image.*

As petroleum composition reflects the current maturity of the Eagle Ford source, it can be used to accuracy constrain burial history. In this case, °API Gravity is a fairly accurate measure of mature and the entire play can be evaluated from reported database values from initial production. Regional trend show a systematic decrease in the amount of exhumation from west to east with over 2.4 km removed in the Maverick Basin with to only ~ 0.9 km removed from the Karnes Trough to the San Marcos Arch. Exhumation east of the Arch is ~1.8 km.

The Eagle Ford provides an ideal system to examine the effects of chemical partitioning upon primary expulsion. By definition, the produced fluids represent material that has been expelled from the kerogen and associate micropores, whereas the rock extracts are assumed to be a mixture of expelled and retained material. A comparison of maturity-equivalent rock extracts (~0.4 to 1.3 $\%R_o$) with produced fluids using ±ESI/APPI-FTICR-MS shows that hydrocarbons (HC), 1S, 1N, 1S1N, 1N1O, 1S1O, and 1N2O species are enriched in the expelled oil whereas 2O-8O species are preferentially retained. With increasing maturation, HC, 1S, 1N, and 1N1O relatively increase in the crude oils and 2O-8O species increase within the rock extracts. Furthermore, these Ox species increase preferentially with toward higher O-content with increasing thermal stress. These observations suggest that the more oxygenated species either are being created with increasing thermal alteration and/or that the most polar species are selectively retained within the kerogen.