

Are coals oil-prone or gas-prone source rocks?

by David Gardiner

Coals are characterised by an abundance of organic material, typically having total organic carbon (TOC) contents exceeding ca.35wt%. However, the composition of this organic carbon is widely variable and often contains a diverse mixture of organic matter types (macerals) which reflect the complex environments where highly organic-rich sediments can form. While coals are generally regarded as “gas-prone” source rocks, coal-sourced oil has been proven in economic accumulations (e.g. Taranaki Basin, New Zealand), but they remain relatively poorly understood geochemically and are only locally productive in Europe (e.g. Middle Jurassic in the Danish North Sea).

From a Petroleum Systems Analysis (PSA) perspective, the composition of fluids expelled from a source rock is fundamentally controlled by the composition of the generated fluids, expulsion efficiency of the rock and PVT conditions. Within coals, the abundance of kerogen may result in the retention of generated oil through kerogen adsorption, which may subsequently be cracked to condensate/gas at higher temperature prior to expulsion from the source rock.

A comparison of kerogen types using the kinetics of Pepper & Corvi (1995) (Fig.1) highlights that a 10m thick non-marine, waxy coal (cuticle, resin, lignin, bacteria; Type D/E kerogen) with a TOC of 35wt% expels a greater volume of oil than a 10m thick marine mudstone with 5wt% TOC. However the volume of expelled gas is much higher from the coal, resulting in a higher gas-oil ratio (GOR) or gas-liquid ratio (GLR) of the expelled products. Quantifying the effect of fluid adsorption on kerogen is also a key uncertainty with regards to effective expulsion volumes, and this could have a major influence on oil expulsion from coals, which are so rich in organic matter. So while Type D/E coals may expel oil, the subsequent gas expulsion may dominate the bulk fluid composition.

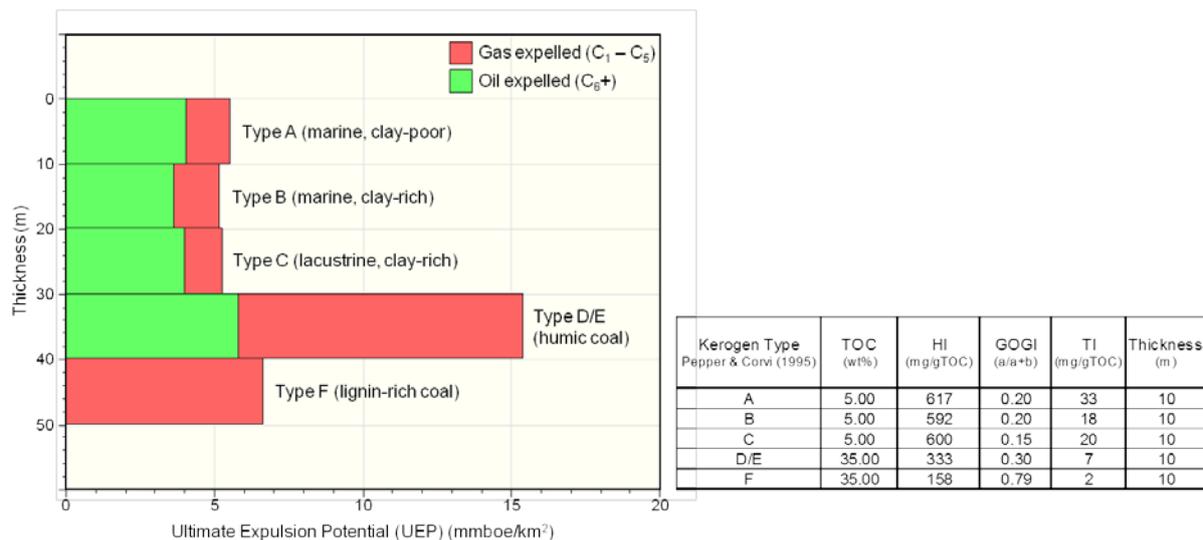


Figure 1: Comparison of the ultimate expulsion potential (UEP) (mmboe/km²) of five industry-standard kerogen types from Pepper & Corvi (1995) highlighting the high volume of expelled oil from humic coals but high GLR of expelled fluids due to the large volume of gas expulsion, calculated in Kinex[®]. Expelled fluid represents oil (C₆₊) and gas (C₁ – C₅) which has migrated from the source interval (retained fluids within the source pore matrix and organic adsorption on kerogen are not shown in this figure and are calculated separately). The model assumes a temperature of 0 – 300°C with a heating rate of 2 °C/My.

Using the same 10m source intervals, Figure 2 compares the theoretical volume of expelled gas (C₁ – C₅) and oil (C₆₊) with increasing maturity for a Type B (Type II), Type D/E (Type III “H”) and Type F (Type III/IV) source rock. The model shows that low GLR (possibly waxy) fluids are expelled from

Type D/E coals when the maturity is 0.8 – 1.0%Ro, but that subsequent gas expulsion occurs at a much higher rate at relatively low maturity above ca.1.1%Ro.

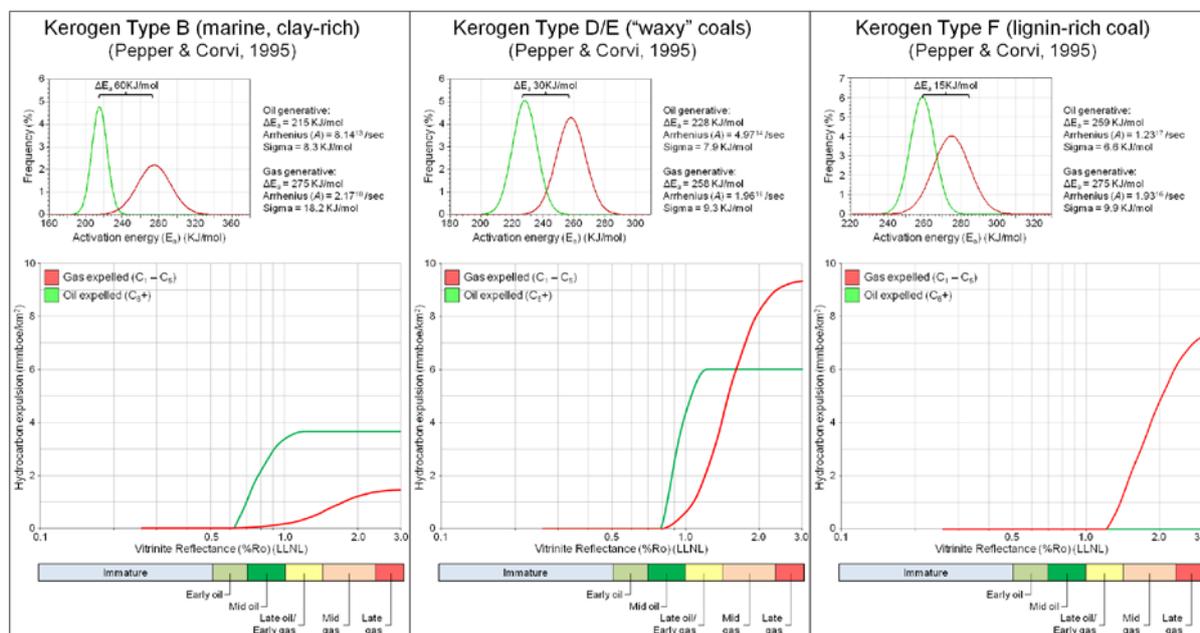


Figure 2: A comparison of three kerogen types from Pepper & Corvi (1995); Type B (Type II) kerogen from marine clastic shale, Type D/E (Type III'H') kerogen from non-marine "ever-wet" coastal plains and Type F (Type III/IV) kerogen from lignin-rich coals deposited in a coastal plain environment. Source inputs are as Figure 1. Vitrinite Reflectance (Lawrence Livermore National Laboratory kinetics) and approximate maturity window equivalence also shown. Note: the bi-phasic fluid expulsion (no condensate). Produced using Kinex®.

So if Type D/E coals can expel oil, why are coal-sourced oil contributions not more commonly recognised? One reason may be an overreliance on larger molecules (biomarkers) and longer-chain compounds in oil-source correlations. Larger molecules are susceptible to thermal-cracking at higher temperatures; the higher E_a required to generate fluid from the oil generative kerogen component in Type D/E coals ($E_a = 228$ KJ/mol) compared to clay-rich Type B ($E_a = 215$ KJ/mol) and carbonate Type A ($E_a = 206$ KJ/mol) shales (not shown) requires higher temperatures before expulsion. This may result in a decrease in the abundance of larger molecules (biomarkers) and longer-chain compounds within coal-sourced fluids due to cracking, and hence an under-appreciation of the charge contribution from coals to the bulk fluid when looking at (C_{20+}) biomarkers alone. Smaller and more thermally-stable compounds such as pristane & phytane, gasoline-range biomarkers and aromatic compounds within oils and condensates may better reflect the charge contribution from coals due to their higher thermal stability and relative abundance in expelled fluids.

But while black oils may be expelled from Type D/E coal intervals over a relatively narrow maturity window, thick coal intervals may have secondary expulsion efficiency effects related to the sedimentological position and connectivity of carrier beds (e.g. sands). Where coals expel fluids into porous inter-beds with poor connectivity within the source rock package (e.g. channel sands) there may be further retention of hydrocarbons. This process may result in the subsequent thermal cracking of oil and an increase in the fluid GLR, although the temperatures required for cracking oil within reservoirs (and presumably in more porous interbeds associated with the coals) are high (ca.>160°C). Therefore the presence and connectivity of interbedded sands acting as carrier beds is likely to be important to the composition of fluid entering the petroleum system.

Many uncertainties remain. Perhaps the oil expulsion window before gas expulsion is too narrow (ca. 0.8-1.0%Ro) in comparison to the broader oil expulsion window associated with Type A to C

kerogens. Perhaps the lower organic sorption capacity of Type D/E kerogen relative to Type F results in earlier (lower temperature?) expulsion, whereby generated liquid hydrocarbons within Type F coals begin to crack in-situ prior to expulsion. Perhaps our kerogen kinetic models are wrong, simplified or inappropriate? The increased abundance of oil-prone coals within the Cenozoic may indicate an evolutionary development of precursor macerals.

Fundamentally, oil expulsion from coals may only be possible where the following factors combine: an abundance of oil-prone kerogen (cuticle, resin, lignin, bacteria; Type D/E kerogen), mid-oil maturity (ca.0.8 – 1.0%Ro_{eq}) and where expulsion efficiency is high enough to prevent oil retention and subsequent cracking. Regardless, coal-sourced oils require careful consideration during Petroleum System Analysis.

References:

PEPPER, A. S. & CORVI, P. J. 1995. Simple kinetic models of petroleum formation Part 1: oil and gas generation from kerogen. *Marine and Petroleum Geology*, 12, 291-321.