

Oil Generation Capacity and Expulsion Window of Humic Coals of Different Age: Implications for Deep Exploration

Petersen, Henrik I.¹, Hans P. Nytoft¹ (1) Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
The evolution of land plants from the Carboniferous towards the Cenozoic has had an overall control on the ability of coals to generate and expel oil. Major coal-sourced oil accumulations are generally associated with Cenozoic coals, whereas Carboniferous coals mainly have been related to gas accumulations. Long-chain aliphatic moieties in the coal structure are required for oil generation, and such aliphatic chains are more prominent within the structure of Jurassic and Cenozoic coals than in older coals, with nC_{20-30+} in particular abundant in Cenozoic coals. In Carboniferous and Permian coals the aliphatic chains are shorter, generally $<nC_{19-24}$. The long-chain aliphatics in Cenozoic coals originate from a matrix of collodetrinite+liptodetrinite, which is abundant in these coals.

A time-lag occurs between onset of petroleum generation and oil expulsion from coals. Only for Cenozoic coals, oil expulsion occurs below a vitrinite reflectance of 0.85% R_o . The start of efficient oil expulsion is dependent on the generation potential and ability to generate long-chain aliphatics, and Cenozoic coals display both the largest oil generation potential and broadest effective oil window. Carboniferous coals are – despite high HI values – inherently gas-/condensate-prone. The overall absence of long-chain aliphatics restricts the oil expulsion efficiency, which agrees with the high extract yields obtained from North Sea Carboniferous coals. Generated liquid petroleum is retained in the coals and upon extraction HI is on average reduced with 30% in these coals. The extracts are dominated by shorter-chain aliphatics.

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Facies Model for Recognition of Planar and Raised Mire Coals and Why the Former are More Oil-prone

Sykes, R.¹, P.E. Johansen² (1) GNS Science, Lower Hutt, New Zealand (2) Applied Petroleum Technology, Kjeller, Norway

Populating multi-dimensional basin models with meaningful source rock data generally requires prediction of the spatial distribution of key kerogen properties (e.g., TOC, HI and GOR) beyond sample locations, based on knowledge of paleoenvironmental and tectonic controls. This tends to be more challenging for humic coaly source rocks, which are particularly heterogeneous at all stratigraphic scales and commonly fluctuate between gas- and oil-prone. Systematic analysis of the bulk chemistry, petrography and pyrolysis-gas chromatography of humic coal seams in several New Zealand basins (Cretaceous–Tertiary) has enabled development of a facies model that distinguishes planar (rheotrophic) and raised (ombrotrophic) mire coals and which can be used to improve prediction of gas:oil ratios in terrestrially sourced petroleum systems.

Planar mire coals are typically thin and characterised by relatively abundant wood tissue within a collodetrinite-rich matrix, together with variable leaf biomass and clastics. In contrast, thick, raised mire coals contain abundant cork tissue in a largely cork-derived, vitrodetrinite-rich matrix, with rare leaf material and clastics. Multivariate analysis has shown that non-volatile paraffinic oil potentials are controlled primarily by the abundance of leaf-derived lipinites (cutinite and liptodetrinite). Planar mire coals (and associated coaly mudstones) tend to have greater oil potentials than raised mire coals as a result of greater leaf biomass input and/or preservation potential under higher groundwater levels. The formation of planar mire and thus more oil-prone coals is favoured by relatively high rates of accommodation increase, whereas raised mire, more gas-prone coals require relatively low–moderate rates of accommodation increase and an ever-wet climate.

Modeling Expelled Petroleum Fluids from Coals

McCormack, Niall¹, Andy Pepper², Mike Adams³ (1) Amerada Hess Corporation, Houston, TX (2) Amerada Hess Corporation, Houston, (3) Amerada Hess Corporation, London,

Expulsion of petroleum from coals has been a controversial subject for a number of years; with protagonists at one end of the spectrum claiming all coals as potential oil expellers while others accept only gas expulsion potential.

We show, using a simple two component scheme, that both arguments are valid to a degree, depending on the depositional environment and organic input that determines kinetics of generation, together with the expulsion efficiency determined largely by the initial HI. It is equally important to model the coal-bearing formation as a population, rather than averaging, as required by many extant modeling approaches.

Linking the kinetic model components with "engineering" type correlations allows us to predict physical properties such as subsurface density, viscosity, and interfacial tension. Unlike aquatic source rocks, relatively few terrestrial coals can expel low GOR (few hundred scf/bbl) oil, with much of the expulsion product corresponding to a higher GOR, volatile product followed by a volumetrically dominant gas charge. Coal-derived petroleum systems are prone to gas-flushing before significant low GOR oil can accumulate. Thus coal-sourced oils (reservoir fluids) are typically characterized by high formation volume factor and low viscosity.

To demonstrate these points we will use examples from the Jurassic Khatatba Formation of the Western Desert, Egypt, and various Australasian basins.

Oils and Oil-prone Coals of the Kutei Basin, Indonesia

Curiale, Joseph A.¹, John Decker², Rui Lin³, Robert J. Morley⁴ (1) Chevron, Sugar Land, TX (2) Chevron, Jakarta, Indonesia (3) Chevron, Bangkok, Thailand (4) PalyNova, Bogor, Indonesia

Previous studies have determined that Miocene and Eocene coals of the Kutei Basin of Indonesia have oil-prone source rock potential. Here we compare nine Miocene and Eocene coals (15Ma to 36Ma) on the island of Borneo with numerous oils recovered from the same basin. Oil-prone source rock potentials of these coals were determined; levels of maturity

were assessed; molecular and isotopic characteristics of the solvent extracts from the coals were evaluated; and these characteristics were compared to those of a selected set of Kutei oils. Our data indicate that several of the coals qualify as oil-prone potential source rocks using conventional interpretive criteria. All are thermally immature or marginally mature, with vitrinite reflectance (VR) values ranging from 0.24% to 0.59%. N-alkane distributions and other molecular characteristics are typical of immature, Tertiary terrigenous organic matter.

Comparison of these Miocene/Eocene coal extracts with the Kutei Basin oils reveals several molecular and isotopic correlations, including the presence of specific molecular markers (e.g., oleananes and oleanenes), distributions (e.g., sterane carbon numbers) and isotopic relationships (e.g., n-alkanes and acyclic isoprenoids). Nevertheless, no single coal is correlatable with any single oil using all of the techniques of this study, indicating that no bona fide and defensible oil-source rock correlation can be made using these coals. Several explanations are available for this observation, including (a) these coals are not sources for any of these oils; (b) the oils arise from multiple sources (including coaly shales); (c) the low maturity levels of these coals preclude a proper correlation; and (d) the molecular content of the Kutei oils is composed of additional material besides that contributed by conventional source rocks (coaly or otherwise). This paper will explore these possibilities in light of our dataset.

Oil-prone Paralic Coals: A Case Study from the Balingian Province of Sarawak, Malaysia

Abdullah, Wan Hasiah¹, Peter Abolins² (1) University of Malaya, Kuala Lumpur, Malaysia (2) PETRONAS Research & Scientific Services Sdn Bhd, 43000 Kajang, Selangor, Malaysia

The petroliferous Balingian Province of offshore Malaysia provides strong evidence for coal as an important source rock for oil as well as gas. These Miocene-Pliocene age coals were deposited within a coastal plain paralic setting. Based on lithofacies association, maceral types and biomarker distributions at least two distinct end member coal-bearing facies were identified from onshore analogues i.e. mangrove-derived coals and (marine-influenced) fluvial-derived coals. Their associated coaly sediments represent the intermediate member. The mangrove-derived coals are generally thin and very rich in mineral matter and high in liptinite content of predominantly suberinitic constituents. The coals and their associated coaly sediments possess good oil generating potential as suggested by pyrolysis and petrographic data. The fluvial-derived coals are relatively thicker and dominated by vitrinite with very low mineral matter and low liptinite content, and are generally less oil-prone compared to the mangrove-derived coals.

The known hydrocarbon distribution of offshore Sarawak appears to be strongly governed by paleogeography within the lower coastal plain: there is a distinct oil trend parallel to the Miocene Cycle II paleocoastline and a prominent gas trend eastwards towards the open sea. This is supported by oil composition. Biomarker distributions of hydrocarbons indicate a gradual reduction in terrigenous input from west to east: the relative abundances of oleanane, bicadinanes, and C₂₉ steranes decrease. There is less variation in biomarker distributions observed on the NW-SE trend, consistent with a northwest-southeast trending paleocoastline. Thus, oil and gas distribution, supported by biomarker fingerprints as well as petrological and lithofacies studies, agree with the proposed paralic coastal plain depositional model for source rocks of the Balingian Province.