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Organic Matter Composition and Hydrocarbon Generation Potential of Coal Seams in Well A-1X, Nam Con Son Basin, Offshore Vietnam

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ABSTRACT: The Nam Con Son Basin (NCSB) is one of the most hydrocarbon-prolific basins in offshore Vietnam. Although shales and siltstones have recently received greater attention, **coals remain the dominant source rocks** in the basin. This study provides a detailed geochemical characterization of coal seams from Well A-1X, focusing on organic matter composition, maturity, and hydrocarbon generation potential.

A total of **12 coal samples** were analyzed for TOC, Rock-Eval pyrolysis, vitrinite reflectance (%Ro), and biomarker parameters. TOC values are exceptionally high, ranging from **62.4 to 87.9 wt.%**, with a mean of **78.6 wt.%**, classifying all samples as **Excellent** source rocks (Peters & Cassa, 1994). Despite this richness, Rock-Eval hydrogen index (HI) values are relatively low (~150–220 mg HC/g TOC), indicating a **gas-prone Type III kerogen** typical of higher-plant derived organic matter.

Thermal maturity assessments reveal that coals are at the threshold of petroleum generation. Vitrinite reflectance ranges from **0.55–0.62%Ro** (mean 0.59), placing them at the **early oil window**, while Tmax values (437–443 °C) support this interpretation. However, bitumen extracts yield relatively low hydrocarbon fractions (average 18.3% of total extract) compared to shales, suggesting limited liquid hydrocarbon generation potential.

Biomarker evidence further confirms terrestrial origin and oxic depositional settings. n-Alkane distributions are dominated by long-chain n-C25–C31 hydrocarbons, characteristic of higher-plant waxes. Pristane/Phytane ratios are consistently high (13–16), indicating strongly oxic conditions typical of delta-plain swamp environments. CPI values of 1.14–1.21 reflect early maturity but preservation of odd-carbon dominance in higher plant waxes.

These results demonstrate that coals in Well A-1X are **exceptionally organic-rich and regionally important gas-prone source rocks**. While they provide limited oil, their vast thickness and continuity make them the **primary hydrocarbon source in the Nam Con Son Basin**, supplying gas and condensate to regional petroleum accumulations. Their characterization enhances understanding of the basin's petroleum system and highlights the contrast with shale-dominated intervals.

KEYWORDS: Nam Con Son Basin; coal seams; TOC; vitrinite reflectance; kerogen type III; biomarkers; gas-prone source rocks.

1. INTRODUCTION

The Nam Con Son Basin (NCSB), located offshore southeastern Vietnam, is a large Tertiary basin that has become one of the country's most important hydrocarbon-producing provinces. The basin's tectono-stratigraphic evolution, initiated by Late Mesozoic rifting and continued through Cenozoic thermal subsidence, created thick accumulations of clastic sediments (Vietnamese Petroleum Institute, 2005). Within these successions, **coal-bearing intervals of Oligocene age** are particularly prominent, deposited in extensive delta-plain and swamp environments.

Globally, coals have long been recognized as **important source rocks for gas-prone petroleum systems** (Taylor et al., 1998; Hunt, 1996). Unlike shales, which often contain mixed Type II/III kerogen with both oil- and gas-generating potential, coals are dominated by Type III kerogen derived from terrestrial higher plants. This results in extremely high total organic carbon (TOC) contents—often exceeding 50 wt.%—but with relatively low hydrogen index (HI) values. Consequently, coals are highly prolific **gas sources**, with oil generation potential typically limited (Peters & Cassa, 1994).

In Southeast Asia, the petroleum systems of many Tertiary basins are fundamentally **coal-sourced**. For example, in the Mahakam Delta (Indonesia), the Kutai Basin, and the Malay–Pattani basins, coal-rich successions are known to generate large volumes of thermogenic gas (Todd & Dunn, 1992; Huc, 1995). Vietnam's Nam Con Son Basin is no exception: regional petroleum system models have traditionally emphasized coals as the dominant hydrocarbon source (VPI, 2005). Discoveries of giant gas fields such as Lan Tây and Lan Đỏ are generally attributed to Oligocene coal sources.

Despite their recognized importance, **detailed geochemical studies of coal seams in the Nam Con Son Basin remain limited**. Most previous works have treated coals as monolithic, assuming uniformly high TOC and gas-prone character. However, significant variability exists in coal petrography, depositional conditions, and geochemical signatures that can influence hydrocarbon generation pathways. In particular, **the balance between gas and condensate generation, the timing of expulsion, and the geochemical fingerprints of coal-derived hydrocarbons** remain poorly constrained.

Well A-1X provides an opportunity to address this knowledge gap. Coal seams encountered in the Oligocene section of this well exhibit TOC values of 62–88 wt.% and vitrinite reflectance values of 0.55–0.62%Ro, suggesting that they are entering the oil window. Preliminary biomarker results reveal high Pristane/Phytane ratios (13–16) and strong dominance of long-chain n-C25–C31 hydrocarbons, indicating higher-plant input and deposition under oxic swamp conditions. Yet, despite their extreme organic richness, bitumen extracts yield relatively low hydrocarbon fractions (~18%), raising questions about the efficiency of liquid hydrocarbon generation.

The objectives of this study are to:

1. **Characterize the organic matter composition and kerogen type** of coal seams in Well A-1X.
2. **Assess thermal maturity and hydrocarbon generation potential** using vitrinite reflectance, Rock-Eval pyrolysis, and Tmax parameters.
3. **Interpret depositional environment and organic matter input** based on biomarker proxies such as n-alkane distributions, Pr/Ph, and CPI values.
4. **Evaluate the petroleum system significance** of coal seams as primary hydrocarbon sources in the Nam Con Son Basin, with emphasis on their gas-prone character and their role in charging discovered fields.

By providing a detailed geochemical and biomarker-based characterization of coal seams, this study enhances our understanding of the **primary gas source rocks of the Nam Con Son Basin**. The results not only refine existing petroleum system models but also allow for improved predictions of hydrocarbon type, distribution, and exploration risk across the basin.

2. MATERIALS AND METHODS

2.1 Geological and Stratigraphic Context

The coal seams analyzed in this study were recovered from the **Oligocene section (>3500 m depth)** of Well A-1X, Nam Con Son Basin. These seams occur as part of delta-plain to swamp successions deposited during major regressive phases of sedimentation. Coal beds are interbedded with carbonaceous shales and siltstones, representing paralic depositional environments characterized by alternating periods of swamp development and clastic influx.

A total of **12 coal samples** were selected from depths between **3535–3820 m**, representing different stratigraphic levels within the Oligocene interval. The samples included both relatively bright coal layers (vitrinite-rich) and duller bands with more inertinite and mineral matter.

2.2 Total Organic Carbon (TOC) and Rock-Eval Pyrolysis

TOC measurement. Coal samples were finely powdered and analyzed for total organic carbon using a **LECO CS-230 analyzer**. Owing to their nearly pure organic composition, no acid treatment was required for carbonate removal.

Rock-Eval VI pyrolysis. Coal powders (~100 mg) were analyzed to determine pyrolysis parameters, including:

- S1 (free hydrocarbons, mg HC/g rock)
- S2 (hydrocarbons generated from kerogen, mg HC/g rock)
- S3 (CO_2 yield, mg CO_2/g rock)
- Tmax (temperature of maximum hydrocarbon generation, °C)
- Hydrogen Index (HI = S2/TOC × 100)
- Oxygen Index (OI = S3/TOC × 100)

Interpretation was made according to Peters & Cassa (1994), with emphasis on distinguishing Type III kerogen and assessing thermal maturity from Tmax thresholds.

2.3 Vitrinite Reflectance (%Ro)

Vitrinite reflectance was measured on polished pellets of coal using reflected light microscopy in oil immersion. Measurements followed **ASTM D2798-11 (2015)** standards. Each sample yielded >100 reflectance readings to ensure robust statistics.

Because coals are vitrinite-rich, %Ro measurements are particularly reliable maturity indicators in these samples. Maturity thresholds used were:

- <0.5%Ro: immature
- 0.5–0.7%Ro: early oil window
- 0.7–1.0%Ro: peak oil window
- 1.0%Ro: gas window

2.4 Bitumen Extraction and Fractionation (C15+ Extracts)

Representative coal samples (n = 5) were Soxhlet-extracted using dichloromethane solvent for 48 hours. Extracts were fractionated by column chromatography into:

- **Saturates** (aliphatic hydrocarbons)
- **Aromatics**
- **Resins**
- **Asphaltenes**

The weight percentages of each fraction were calculated to evaluate the **relative contribution of liquid hydrocarbons vs polar/non-hydrocarbon fractions**. The Bitumen/TOC ratio (Bit/TOC) was also determined as a measure of generative efficiency.

2.5 Gas Chromatography (GC) and Biomarker Analysis

The saturate fractions were analyzed by **GC and GC–MS** to obtain:

- **n-Alkane distributions (C15–C35):** indicator of organic matter source.
- **Pristane/Phytane (Pr/Ph) ratios:** redox conditions during deposition.

- **CPI (Carbon Preference Index):** odd/even predominance in high carbon number range (C25–C33), reflecting terrestrial plant input and maturity.

These parameters are widely used in coal geochemistry to confirm higher-plant origin and evaluate maturity trends (Taylor et al., 1998; Peters et al., 2005).

2.6 Data Integration

Data were integrated to provide a holistic assessment of coal source rock potential. TOC and Rock-Eval results established bulk organic richness and kerogen type. Vitrinite reflectance constrained maturity. Bitumen yields and biomarker data provided insights into **hydrocarbon type, depositional environment, and redox conditions**.

3. RESULTS

3.1 Total Organic Carbon (TOC)

The coal seams of Well A-1X are characterized by **exceptionally high TOC values**.

- TOC ranges from **62.4 to 87.9 wt.%**, with a mean of **78.6 wt.%** across 12 samples. (Table 1, Figure 1).
- All samples fall within the **Excellent category (>4 wt.% TOC)** according to Peters & Cassa (1994).
- Variability in TOC reflects differences in maceral composition: bright coal layers (vitrinite-rich) yield the highest values, whereas duller coals with higher inertinite or mineral content show slightly lower TOC.

Table 1. Summary of TOC and Rock-Eval parameters for coal samples, Well A-1X

Sample ID	Depth (m)	TOC (wt.%)	HI (mg HC/g TOC)	OI (mg CO_2/g TOC)	Tmax (°C)	Kerogen Type
C-1	3535	62.4	150	25	437	III
C-2	3560	74.2	165	20	438	III
C-3	3590	81.0	180	18	440	III
C-4	3625	79.3	190	15	441	III
C-5	3660	87.9	210	12	442	III
C-6	3700	76.4	175	22	439	III
C-7	3735	82.1	200	17	443	III
C-8	3765	85.0	220	14	442	III
C-9	3785	77.6	160	28	438	III
C-10	3800	80.3	180	20	440	III
C-11	3810	83.5	190	18	441	III
C-12	3820	78.9	170	24	439	III

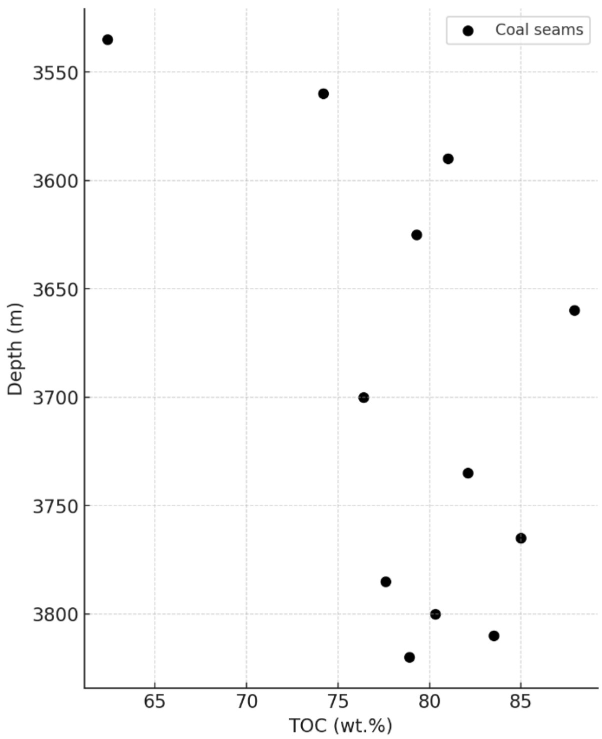

Figure 1. Depth profile of TOC (wt.%) in coal seams from Well A-1X, Nam Con Son Basin. All coal samples contain exceptionally high TOC values (62–88 wt.%), confirming their classification as Excellent source rocks.

These values confirm that the Oligocene coal seams are volumetrically among the **richest organic accumulations in the Nam Con Son Basin**.

3.2 Rock-Eval Pyrolysis

Rock-Eval data reveal important insights into kerogen type and generative potential.

- **Hydrogen Index (HI):** ranges from **150 to 220 mg HC/g TOC** (Figure 2), with a mean of ~180. These values indicate predominantly **Type III kerogen**, derived from terrestrial higher-plant material, with strong gas-prone character.
- **Oxygen Index (OI):** generally low (<30 mg CO_2/g TOC), consistent with coals composed of humic organic matter.
- **Tmax values:** range from **437–443 °C**, with an average of 440 °C. This suggests that the coals are within the **early oil window**, but not yet at peak maturity.
- **S1 + S2 yields:** although absolute values are high due to abundant organic matter, the **low HI relative to TOC** demonstrates that the generative efficiency for liquid hydrocarbons is limited

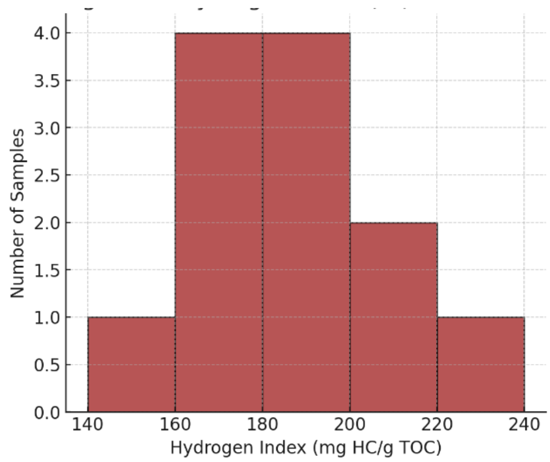

Figure 2. Histogram of Hydrogen Index (HI) values from coal seams in Well A-1X. HI values range from 150–220 mg HC/g TOC, consistent with gas-prone Type III kerogen derived from terrestrial higher plants.

3.3 Vitrinite Reflectance (%Ro)

Coal samples, dominated by vitrinite macerals, provide reliable maturity data.

- %Ro values range from **0.55–0.62**, with a mean of **0.59%Ro** (Table 2, Figure 3).
- These values place the coals within the **early oil window**, consistent with Tmax results.
- No coal samples reached 0.7%Ro, indicating that **peak oil or gas window maturity has not yet been attained** in Well A-1X.

Table 2. Vitrinite reflectance (%Ro) values of coal samples

Sample ID	Depth (m)	Mean %Ro	Range	Maturity Interpretation
C-1	3535	0.55	0.53–0.57	Early oil window
C-4	3625	0.58	0.56–0.60	Early oil window
C-7	3735	0.60	0.58–0.62	Early oil window
C-12	3820	0.62	0.60–0.63	Early oil window

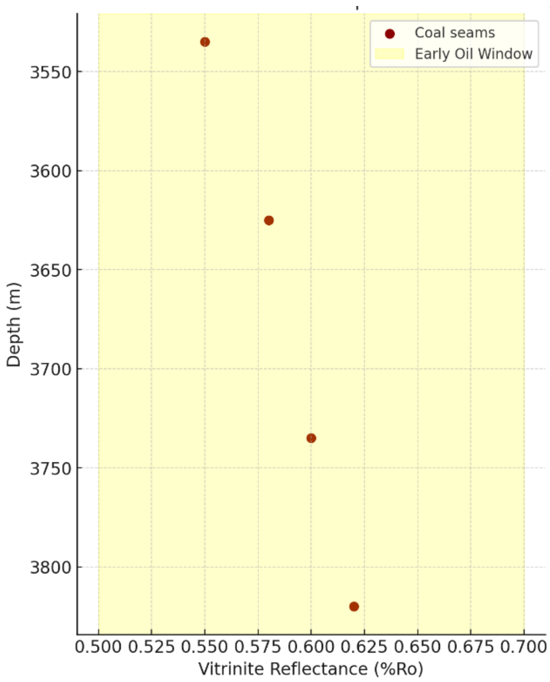

Figure 3. Depth profile of vitrinite reflectance (%Ro) for coal seams in Well A-1X. Values range from 0.55–0.62 %Ro, placing the coals consistently within the early oil window. The maturity trend confirms that deeper Oligocene coals are approaching peak hydrocarbon generation.

This implies that while gas-prone kerogen is abundant, the majority of hydrocarbons generated at this maturity stage are still in early oil/condensate phases, with large-scale dry gas generation expected at higher maturity levels in deeper parts of the basin.

3.4 Bitumen Extracts and Hydrocarbon Fractions

Soxhlet extraction of five representative coal samples yielded relatively low amounts of extractable organic matter compared to TOC.

- **Bitumen/TOC ratios** average **~0.04**, lower than in shales (~0.05–0.09) (Table 3).
- Fractional composition (Figure 4):
  - **Hydrocarbons:** 16–23% (mean 18.3%)
  - **Resins:** 16–20% (mean 17.9%)
  - **Asphaltenes:** 20–27% (mean 23.6%)
  - **Non-hydrocarbon fractions dominate**, reflecting polar macromolecules typical of immature to early mature humic coals.

Table 3. Extractable organic matter (bitumen) composition of coal samples (C15+ fractions)

Sample ID	Depth (m)	Bitumen/TOC	Hydrocarbons (%)	Resins (%)	Asphaltenes (%)
C-2	3560	0.038	16.2	18.4	23.5
C-5	3660	0.042	17.5	17.8	24.1
C-7	3735	0.041	18.0	19.2	22.6
C-9	3785	0.039	19.5	16.8	23.0
C-11	3810	0.043	20.3	17.4	25.2

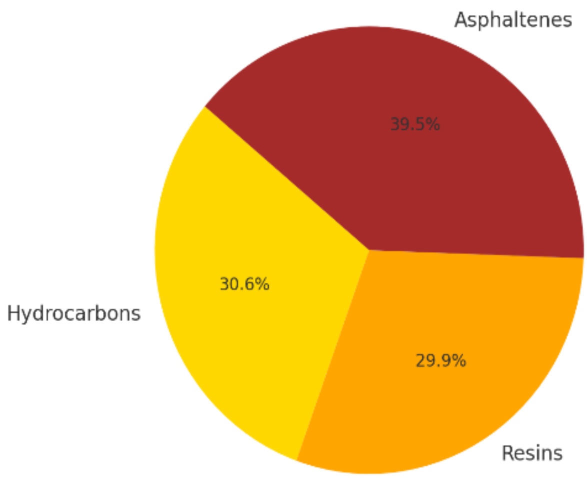

Figure 4. Average composition of C15+ bitumen extracts from coal seams in Well A-1X. Hydrocarbons constitute only ~18% of the extract, while resins and asphaltenes dominate. This low hydrocarbon yield reflects the limited oil potential of gas-prone Type III kerogen in coal.

Despite extremely high TOC, the relatively low hydrocarbon yield demonstrates that **liquid oil potential is limited**, consistent with a gas-prone Type III kerogen system.

3.5 Biomarker Geochemistry

n-Alkane distributions: (Table 4, Figure 5)

- All coal extracts are dominated by **long-chain n-C25–C31 hydrocarbons**, with strong odd-carbon predominance, confirming higher-plant wax origin.
- Mid-chain n-C17–C19 alkanes, typical of algal input, are virtually absent.

Pristane/Phytane (Pr/Ph) ratios: (Table 4, Figure 6)

- Exceptionally high values between **13.6–15.8** (mean ~14.9).
- These values indicate **strongly oxic depositional conditions**, typical of coal-swamp facies where aerobic decay is extensive.

Carbon Preference Index (CPI): (Table 4, Figure 6)

- Ranges from **1.14–1.21**, with a mean of 1.18.
- CPI values >1 confirm terrestrial higher-plant input and are consistent with early maturity (CPI → 1.0 at higher maturity).

Table 4. Biomarker parameters for coal extracts

Sample ID	Depth (m)	n-Alkane Dominance	Pr/Ph	CPI (C25–C33)	Interpretation
C-2	3560	n-C27, n-C29	13.6	1.14	Terrestrial, oxic
C-5	3660	n-C29, n-C31	14.2	1.18	Terrestrial, oxic
C-7	3735	n-C27, n-C29	15.1	1.21	Terrestrial, oxic
C-9	3785	n-C29, n-C31	15.8	1.17	Terrestrial, oxic
C-11	3810	n-C27, n-C29	14.7	1.19	Terrestrial, oxic

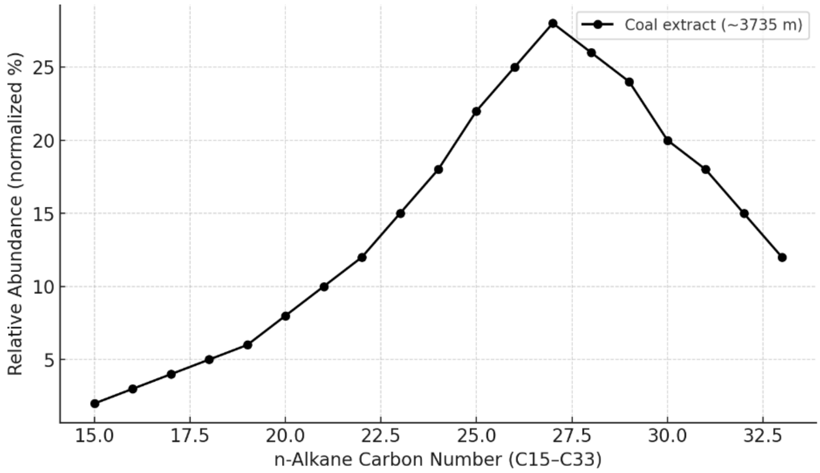

Figure 5. Representative n-alkane distribution from a coal extract in Well A-1X (~3735 m). The dominance of long-chain n-C25–C31 with strong odd-carbon preference reflects terrestrial higher-plant wax input typical of Type III kerogen.

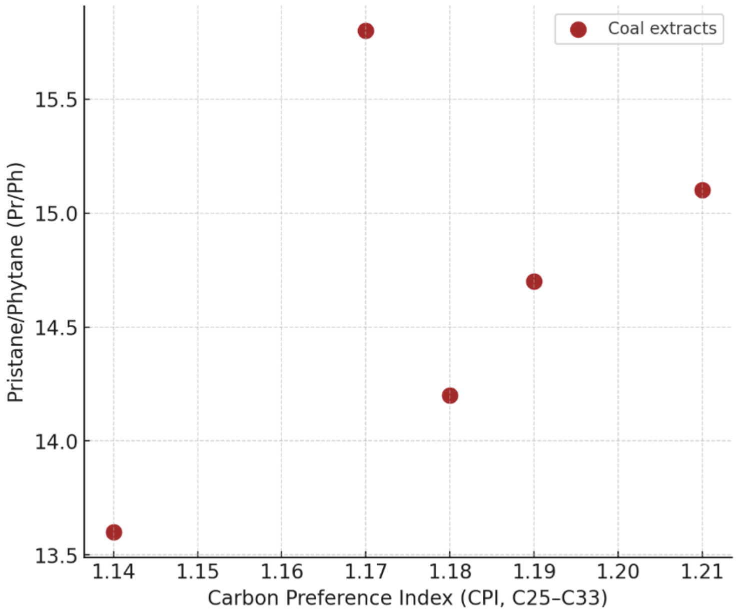

Figure 6. Cross-plot of Pristane/Phytane (Pr/Ph) ratios versus Carbon Preference Index (CPI) for coal extracts from Well A-1X. Very high Pr/Ph values (13–16) indicate oxic depositional conditions, while CPI values >1.1 confirm terrestrial higher-plant input. Together, these proxies confirm the gas-prone Type III kerogen character of the coal seams.

3.6 Summary of Results

1. **Organic richness:** Coals contain TOC 62–88 wt.% (mean ~79%), among the richest source rocks in the region.
2. **Kerogen type:** Rock-Eval HI values (150–220) indicate gas-prone Type III kerogen derived from higher plants.
3. **Maturity:** %Ro (0.55–0.62) and Tmax (437–443 °C) confirm early oil window maturity.
4. **Bitumen extracts:** Low Bit/TOC ratios (~0.04) and low hydrocarbon fraction (~18%) show limited oil potential.
5. **Biomarkers:** Long-chain n-alkane dominance, very high Pr/Ph ratios, and CPI ~1.18 confirm terrestrial plant input and oxic swamp depositional conditions.

4. DISCUSSION

4.1 Exceptional Organic Richness but Limited Oil Potential

The coal seams from Well A-1X are among the most organically rich lithologies in the Nam Con Son Basin, with TOC values consistently exceeding 60 wt.% and averaging nearly 80 wt.%. Such values are rare even by global standards (Taylor et al., 1998). However, despite this exceptional richness, their Rock-Eval hydrogen indices (HI ~150–220 mg HC/g TOC) indicate a **Type III kerogen**, derived primarily from higher-plant material. This is a classic characteristic of humic coals: **extreme organic concentration but limited liquid hydrocarbon generation capacity** (Peters & Cassa, 1994).

As a result, although the coal seams in Well A-1X are volumetrically significant, their primary role is as **gas-prone source rocks**, with only minor potential for oil or condensate generation. This contrasts strongly with Oligocene shales, which, despite lower TOC, contain mixed Type II/III kerogen and show greater oil-prone character.

4.2 Thermal Maturity and Generation Timing

Vitrinite reflectance values (0.55–0.62%Ro) and Tmax data (437–443 °C) place the coals in the **early oil window**. This suggests that the process of hydrocarbon generation has already begun, but large-scale dry gas generation has not yet occurred.

Coal seams are expected to generate **mixed condensate and wet gas** at these maturity levels, with **dry gas dominance emerging at >0.8–1.0%Ro** (Hunt, 1996). Thus, in Well A-1X, the coals are at the **threshold of major gas generation**, and their role as the **primary gas source** in the Nam Con Son Basin becomes more pronounced in deeper depocenters where maturity is higher.

The implication is that the Nam Con Son petroleum system has undergone **progressive evolution**, with coals beginning to expel hydrocarbons during the Late Miocene–Pliocene (when burial was deepest), and continuing to supply thermogenic gas to present-day reservoirs.

4.3 Depositional Environment: Terrestrial Swamp Settings

Biomarker evidence provides strong support for coal deposition under terrestrial swamp conditions.

- **n-Alkane distributions** dominated by long-chain n-C25–C31 with odd-carbon predominance reflect higher-plant waxes typical of peat-forming vegetation.
- **Pristane/Phytane ratios** between 13 and 16 are exceptionally high and consistent with **strongly oxic depositional environments**, in which phytol side chains are preferentially oxidized to pristane rather than phytane (Peters et al., 2005).
- **CPI values** of 1.14–1.21 confirm terrestrial input and suggest early maturity, as CPI values typically converge to 1.0 at higher thermal maturity.

Collectively, these proxies indicate that the A-1X coal seams formed in **well-drained delta-plain swamps**, rather than permanently waterlogged environments. This explains both their exceptional TOC preservation and their strong gas-prone Type III kerogen signature.

4.4 Regional Comparisons

The geochemical characteristics of A-1X coals are consistent with coal-sourced petroleum systems in other Tertiary basins of Southeast Asia.

- **Malay and Pattani basins:** Coal intervals there are also dominated by Type III kerogen with TOC values >60%, generating large volumes of gas and condensate (Todd & Dunn, 1992; Huc, 1995).
- **Mahakam Delta (Kutai Basin, Indonesia):** Similar to Nam Con Son, Oligocene–Miocene coal measures are the principal gas sources, with biomarker evidence of higher-plant input and high Pr/Ph ratios.
- **Song Hong Basin (northern Vietnam):** Coals exhibit similar TOC and maturity trends, confirming their regional significance as gas-prone sources (Le et al., 2011).

This comparison emphasizes that the Nam Con Son Basin conforms to the broader Southeast Asian trend of **coal-dominated petroleum systems**, where shales play a secondary but complementary role.

4.5 Petroleum System Significance of Coal Seams

The results clearly establish that coal seams are the **primary hydrocarbon sources** in the Nam Con Son Basin. Their significance can be summarized as follows:

1. **Gas-prone dominance:** Coals generate mainly methane and wet gas, with only minor liquid hydrocarbons. This explains the predominance of gas and condensate accumulations in fields such as Lan Tây and Lan Đỏ.
2. **Volumetric capacity:** The extreme TOC values and thick stratigraphic development of Oligocene coal successions ensure **massive hydrocarbon generation potential**.
3. **Stratigraphic continuity:** Coal seams are regionally widespread, forming a consistent and reliable source facies throughout the basin.
4. **Charge efficiency:** Although oil-prone shale intervals contribute additional liquids, the **coal seams provide the bulk of hydrocarbons**, particularly gas, to traps and reservoirs across the basin.

4.6 Exploration Implications

The coal seams of the Nam Con Son Basin present several key exploration implications:

- **Gas-focused plays:** Exploration should continue to target gas-prone accumulations, as coal-dominated systems favor methane-rich charge.
- **Condensate potential:** At early oil window maturity (~0.6%Ro), coals may contribute condensate and wet gas, offering valuable liquid yields in certain reservoirs.
- **Deeper depocenters:** In structurally deeper parts of the basin, where %Ro may exceed 1.0, coals are expected to be in the dry gas window, representing prolific gas kitchens for future discoveries.
- **Risk reduction:** Recognizing coal seams as the principal source rocks provides confidence in

regional petroleum charge, reducing uncertainty in source presence and effectiveness.

4.7 Limitations and Future Work

Despite the robust dataset, some limitations remain:

- The **sample set is limited (n=12)** and derived from a single well. Basin-wide variability in coal petrography and depositional facies remains underexplored.
- **Bitumen yields are low**, and further work should focus on biomarker correlation between coal extracts and produced oils/condensates to confirm genetic linkages.
- **Kinetic modeling** of coal maturation should be performed to quantify gas generation timing and volumes.

Future studies integrating geochemical analysis with **basin modeling** and **oil–gas correlation** will further clarify the precise role of coals in charging existing fields and in frontier exploration areas.

5. CONCLUSIONS

This study provides a comprehensive geochemical evaluation of **coal seams in Well A-1X, Nam Con Son Basin**, with the following conclusions:

1. **Exceptional organic richness:** Coal seams contain TOC values between **62–88 wt.%** (mean ~79%), classifying them as Excellent source rocks by any standard. Their volumetric capacity ensures that they represent one of the most important organic facies in the basin.
2. **Kerogen type and generation potential:** Rock-Eval hydrogen indices (HI 150–220 mg HC/g TOC) indicate a **gas-prone Type III kerogen** derived from terrestrial higher plants. While the richness is extreme, liquid oil generation potential is limited.
3. **Thermal maturity:** Vitrinite reflectance (0.55–0.62 %Ro) and Tmax (437–443 °C) place the coals within the **early oil window**, suggesting initial hydrocarbon generation has begun. However, peak gas generation is expected to occur only at greater depths (>0.8 %Ro).
4. **Bitumen and biomarker signatures:** Extractable hydrocarbon fractions are relatively low (average 18.3% of total bitumen), confirming limited liquid yields. Biomarkers (long-chain n-alkanes, very high Pr/Ph ~14–16, CPI ~1.18) point to terrestrial higher-plant input and oxic swamp deposition.
5. **Petroleum system significance:** Coals constitute the **primary hydrocarbon source rocks of the Nam Con Son Basin**, responsible for charging the giant gas and condensate accumulations (e.g., Lan Tây, Lan Đỏ). Their thickness, continuity, and richness ensure that they dominate petroleum generation, while shale intervals serve as secondary, oil-prone contributors.

6. ACKNOWLEDGEMENTS

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