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## Devonian strata of the Amazonas Basin: Organic geochemistry and palynofacies of outcrops of the Barreirinha Formation's shales - Potential for generation of hydrocarbons

*Devoniano da Bacia do Amazonas: geoquímica orgânica e palinofácies de estratos aflorantes da Formação Barreirinha - potencial para geração de hidrocarbonetos.*

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**Abstract:** During the Upper Devonian, a thick package of organic matter-rich shales belonging to the Barreirinha Formation developed in the Amazon Basin. Twenty-six samples collected from two shales outcrops on the southern edge of the basin were studied using Rock-Eval pyrolysis and palynofacies, and interpreted using inferential and multivariate statistics. The total organic carbon (TOC) values vary from 1.47 to 9.50%, indicating good to excellent production conditions of organic matter. The generating potential (S<sub>2</sub>) values range from 3.92 to 33.98 mg HC/g rock, denoting a generating potential that falls between moderate to excellent. These samples present high hydrogen index (HI) and low oxygen index (OI) values, indicating predominantly type II kerogen. The low free hydrocarbon values (S<sub>1</sub>) and the maximum pyrolysis temperature (<440 °C) may be associated with their thermal immaturity. The organic component analysis shows a predominance of amorphous organic matter (AOM) and palynomorphs and marine components predominate over terrestrial components, indicating deposition within a marine environment. Cluster analysis established two palynofacies correlated to stratigraphic intervals associated with sea-level variability. The ternary diagrams of organic components indicate that the depositional paleoenvironment was that of a distal platform that varied between oxic and anoxic conditions.

**Keywords:** Organic Geochemistry; palynofacies; Barreirinha Formation.

**Resumo:** Durante o Devoniano Superior, um espesso pacote de folhelhos ricos em matéria orgânica pertencentes à Formação Barreirinha, desenvolveu-se na Bacia do Amazonas. Vinte e seis amostras coletadas em dois afloramentos de folhelhos da borda sul da bacia, foram estudadas por meio da pirólise Rock-Eval e palinofácies, e interpretados com o auxílio da estatística inferencial e multivariada. Os valores de carbono orgânico total (COT) variam de 1,47 a 9,50 %, indicando boa a excelente condição de preservação da matéria orgânica. Os valores de potencial de geração (S2) variam de 3,92 a 33,98 mg HC/ g rocha, denotando potencial gerador entre moderado a excelente. As amostras apresentam altos valores de índice de hidrogênio (IH) e baixos valores de índice de oxigênio (IO), indicando querogênio predominantemente do tipo II. Os baixos valores de hidrocarbonetos livres (S1) e de Temperatura Máxima da Pirólise (<440°C) podem indicar imaturidade termal. A análise de componentes orgânicos mostra predominância de matéria orgânica amorfa (MOA) e palinomorfos; e uma predominância de componentes marinhos sob terrestres, indicando deposição em ambiente marinho. A análise de cluster estabeleceu duas palinofácies correlacionadas a intervalos estratigráficos associados a variação do nível do mar. Os diagramas ternários de componentes orgânicos inferem que o paleoambiente deposicional era uma plataforma distal com variação óxico-anóxica.

**Palavras-chave:** Geoquímica orgânica; Palinofácies; Formação Barreirinha.

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## 1. Introduction

Since the 1950s, systematic studies on the organic geochemistry of the Devonian strata of the Amazonas Basin have been closely linked to research conducted by Petrobras. Previous research providing data on palynology, organic geochemistry (thermal maturation, generating potential), and depositional paleoenvironment demonstrates that the Barreirinha Formation is the location in the Amazonas Basin with concentrated radioactive shales and that this formation contains the layer most favourable for the generation of hydrocarbons (Garcia, 2014; Calderón, 2017; Góes *et al.*, 2021; Souza *et al.*, 2021; Góes *et al.*, 2022). Characterized by its great thickness, the Barreirinha Formation contains abundant and highly mature organic carbon. This deposit is the result of a major marine transgression that took place at the end of the Devonian (Frasnian and Famennian) because of the epicontinental sea-level oscillations that developed in Brazil during this period (Dino *et al.*, 2002; Souza *et al.*, 2013; Sedat *et al.*, 2016; Kabanov and Jiang, 2020).

This work integrates inferential and multivariate statistical analyses and organic geochemistry to determine the type of kerogen, and to analyze the palynofácies, paleodepositional conditions, thermal maturity, and hydrocarbon generation potential of the black shales in the Barreirinha Formation which were deposited at along two outcrops located near the city of Rurópolis – Pará – Brazil.

### 1.1 Regional geology

The current morphology of the Amazonas Basin is due to the heterogeneity of its basement lithology, which is related to Paleozoic tectonic-sedimentary events. The Amazonas Basin (Figure 1) is located in northern Brazil between the Purus and Gurupá structural arcs, covering part of the states of Pará, Amazonas, Amapá, and Roraima. It is a syncline basin and has an area of approximately 600,000 km<sup>2</sup> (Cunha *et al.*, 2007; Caputo and Soares, 2016). This basin is part of the group of Brazilian intracratonic basins, developed during the stabilization phase of the South American Platform. It presents a sizeable sedimentary package approximately 5000 m thick deposited from the Paleozoic to the Cenozoic (Loboziak *et al.*, 1997; Cunha *et al.*, 2007; Ferreira *et al.*, 2015; Caputo and Soares, 2016) (Figure 2).

Divided into two mega-sequences, the first sedimentary package of the Amazonas Basin dates to the Palaeozoic age and the second package is from the Mesozoic-Cenozoic ages (Cunha *et al.*, 2007). Four sequences related to their depositional ages and stratigraphic stacking separated the Palaeozoic mega sequence (Figure 2) into the Ordovician-Devonian, Devono-Tournaisian, Neovisean, and Pennsylvanian-Permian sequences.

The Curuá and Urupadi Groups belong to the Devono-Tournaisian Sequence and are characterized by shallow marine sedimentation superimposed by glacial incursions. Due to its heterogeneity, the Curuá Group is divided into the following formations: (I) Barreirinha (marine platform), (II) Curiri (glacial to periglacial), and (III) Oriximiná (shallow/river marine).

Among these formations, the Barreirinha Formation is considered the primary source rock in the Amazonas Basin (Cunha *et al.*, 2007). The deposition of this formation is related to a rapid relative rise in sea level associated with a significant marine transgression that occurred on the South American Shelf during the Frasnian. Therefore, the formation comprises a thick section of grey to black bituminous, radioactive, laminated, breakable shales (Cunha, 2000; Caputo, 1984; Ferreira *et al.*, 2015).

## LOCATION MAP

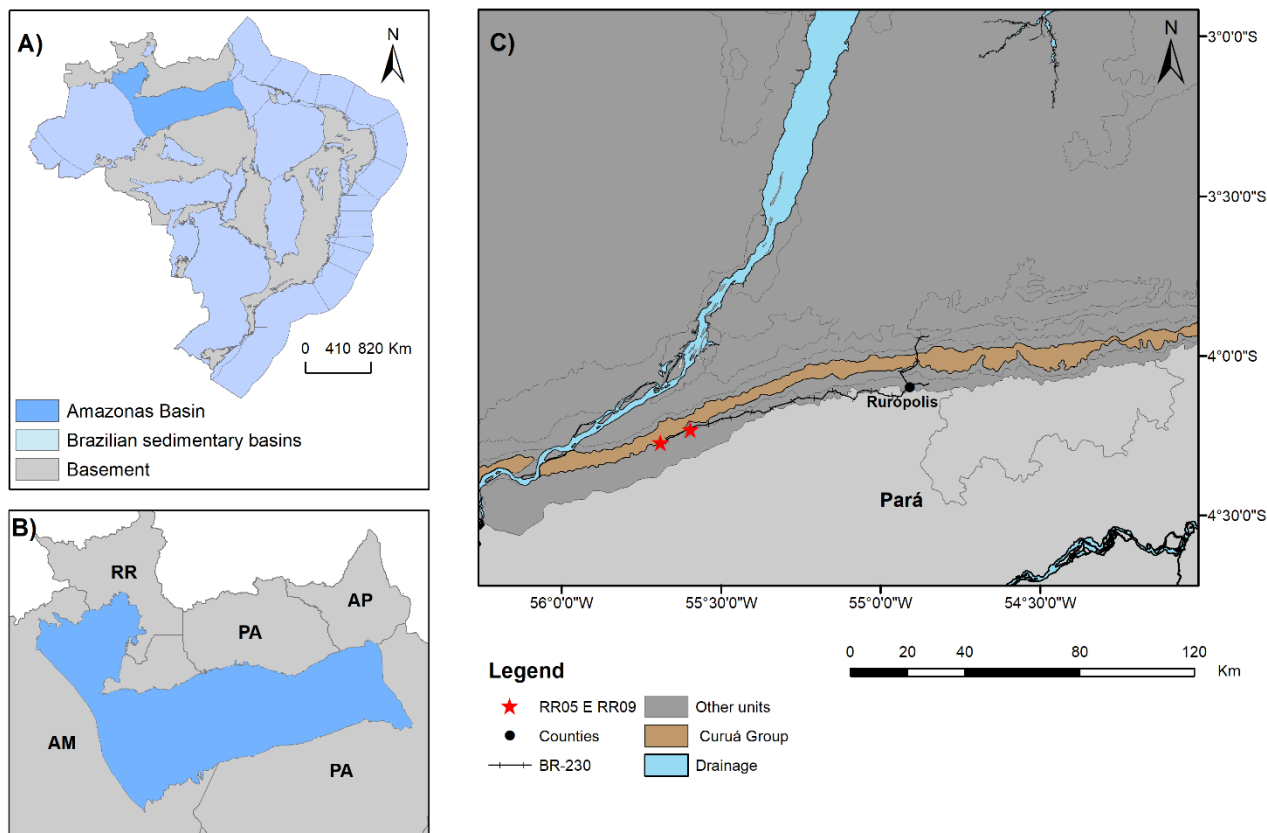


Figure 1 - Location map; A) map of Brazilian sedimentary basins, emphasizing the Amazonas Basin; B) states that intersect the Amazonas Basin; C) geological map of the sample collection site.  
Source: Adapted from CPRM (2020).

## 2. Materials and methods

### 2.1 Description of sampling

To recover the entire sedimentary package corresponding to the Barreirinha Formation, twenty-six samples were collected from two outcrops, RR05 and RR09, on the southern edge of the Amazonas Basin, close to highway BR-230, in the municipality of Rurópolis-PA (Figure 1). Fifteen samples were collected at outcrop RR05, and eleven samples were collected at outcrop RR09. The local geology of both outcrops was similar, with the presence of dark grey to black, fissile, and laminated shales. Small trenches were dug in the outcrops to help collect the most well-preserved samples and remove possible contaminants, such as branches and roots. The samples were wrapped in aluminum foil, placed in previously labelled pure cotton bags, and taken to the LEPETRO laboratory, Excellence in Geochemistry: Petroleum, Energy, and Environment, at the Geosciences Institute (IGEO) located at the Federal University of Bahia (UFBA) to perform the analyses of Total Organic Carbon (TOC), Rock-Eval Pyrolysis and palynology.

### 2.2 Rock-Eval Pyrolysis

For this analysis, 100 mg of each sample were sieved through a 0.177 mm sieve and then placed in tin capsules. Capsules were then analyzed with a Rock-Eval 6 instrument following the procedure proposed by Espitalié *et al.* (1977) and Lafargue *et al.* (1998) to determine the TOC as well as the peaks for S1, S2, S3, Tmax, the Hydrogen Index (HI) and the Oxygen Index (OI).

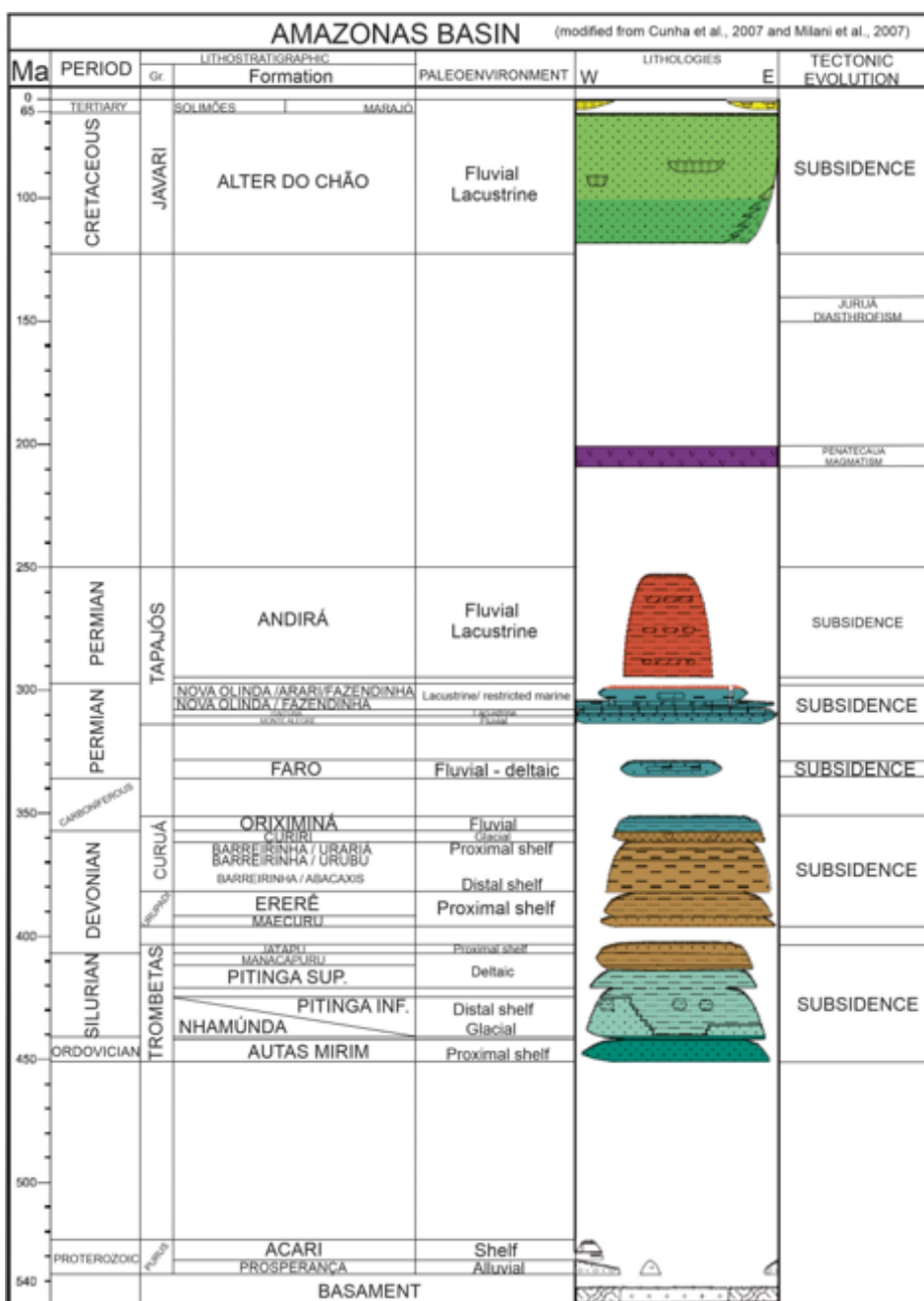


Figure 2 – Stratigraphic chart of the Amazonas Basin.  
 Source: Souza et al. (2021), adapted from Cunha et al. (2007) and Milani et al. (2007).

### 2.3 Palynology

#### 2.3.1 Isolation of kerogen

The procedure adopted for kerogen isolation followed the standard non-oxidative procedures described by Tyson (1995), Mendonça Filho *et al.* (2010, 2011, 2014) and Poggio *et al.* (2019). Routine palynological techniques involved manual maceration of the samples before they were sieved between 1.0 and 2.8 cm. Then, they were acidified with hydrochloric acid (37%) and hydrofluoric acid (40%) to remove carbonates and silicates, respectively. Between successive acidifications, the samples were washed with distilled water to remove excess acid. Kerogen separation was performed using a zinc chloride solution (density from 1.9 to 2 g/cm<sup>3</sup>). To halt this process, commercial alcohol was added to the samples, and the particulate organic fraction was then recovered. Finally, the isolated kerogen was mounted on thin glass slides using Entellan and sealed with coverslip.

### 2.3.2 Analysis of palynofacies

Particulate organic matter was evaluated by optical microscopy through the analysis of organopalynological slides. This analysis used a Zeiss microscope (Model A2 m) that was coupled to a computer and utilized white light and incident blue/ultraviolet light (fluorescence mode), with different magnification objectives (10×, 20×, 50×, 100×). To obtain photomicrographs of the slides, an AxioCam MRc digital camera coupled to the microscope was used.

In this evaluation, 300 organic components (size >10 µm) were counted and identified in the 20x objective, following the methodology adapted from Tyson (1995) and Poggio *et al.* (2019). The state of preservation, shape, structure, coloration, and fluorescence of the organic constituents were also analyzed through qualitative analysis. The organic components were grouped following the three main general classification groups of organic matter: (1) amorphous organic matter (AOM), (2) palynomorphs, and (3) phytoclasts. (Tyson, 1995, Mendonça Filho & Gonçalves 2017; Poggio *et al.*, 2019).

### 2.4 Statistical analysis

The data generated by the palynological analyses were processed using the Bioestat 5.3 and Past 4.03 programs. Cluster analysis (Cluster) and principal component analysis (PCA) were performed on the main groups of organic matter. In addition, the Pearson correlation coefficient 'r' between all parameters was generated to quantify the relationship between them.

## 3. Results and discussions

### 3.1 Rock-Eval Pyrolysis

The results of the analyses led to the evaluation of the thermal maturity and the depositional paleoenvironment of the sampled shales as well as the potential for hydrocarbon generation. The analytical results are shown in Table 1.

Table 1 - Results of the Rock-Eval pyrolysis analysis of samples from the Barreirinha Formation, southern edge, Amazonas Basin.

SAMPLES	Height of samples (m)	Rock-Eval Pyrolysis						
		TOC (%)	Free Hydrocarbons (S <sub>1</sub> - mg HC/g rock)	Source Potential (S <sub>2</sub> - mg HC/g rock)	Carbon Dioxide (S <sub>3</sub> - mg CO <sub>2</sub> /g rock)	Maximum temperature (T <sub>max</sub> - °C)	Hydrogen index (HI - mg HC/g TOC)	Oxygen index (OI - mg CO <sub>2</sub> /g TOC)
RR 05-213	0	2.88	0.11	7.22	1.85	428	251	64
RR 05-214	1	3.41	0.29	9.62	0.26	424	282	8
RR 05-215	2	2.55	0.20	8.50	0.14	425	333	5
RR 05-216	3	4.95	0.19	19.67	0.41	425	397	8
RR 05-217	4	2.37	0.17	8.03	0.12	429	339	5
RR 05-218	5	2.03	0.15	4.69	0.18	426	231	9
RR 05-219	6	1.59	0.07	3.92	0.11	426	247	7
RR 05-220	7	3.32	0.22	10.70	0.23	425	322	7
RR 05-221	8	2.86	0.14	6.71	0.42	424	235	15
RR 05-222	9	4.09	0.12	10.23	64.00	425	250	16
RR 05-223	10	2.31	0.12	5.80	0.14	427	251	6
RR 05-224	11	9.50	0.58	33.83	1.02	421	356	11
RR 05-225	12	4.75	0.26	18.71	0.28	424	394	6

RR 05-226	13	4.08	0.28	14.24	0.46	422	349	11
RR 05-227	14	5.34	0.34	17.81	0.75	425	334	14
RR 09-278	0	2.38	0.20	5.44	0.17	424	229	7
RR 09-279	1	3.72	0.04	9.96	0.31	426	268	8
RR 09-280	2	3.90	0.38	14.23	0.15	430	365	4
RR 09-281	3	1.47	0.10	2.42	0.09	426	165	6
RR 09-282	4	6.80	0.49	26.84	0.87	424	395	13
RR 09-283	4.5	9.33	0.74	33.98	1.38	422	364	15
RR 09-284	5	6.93	0.46	20.10	2.26	424	290	33
RR 09-285	5.5	7.69	0.38	24.86	1.67	423	323	22
RR 09-286	6	6.12	0.29	27.80	2.07	430	454	34
RR 09-287	6.5	5.11	0.24	15.63	2.50	426	306	49
RR 09-288	7	4.31	0.20	18.48	0.94	428	429	22

Source: author (2026).

The total organic carbon (TOC) contained in the collected samples varied between 1.47 and 9.50%. According to the ranking scheme from Peters & Cassa (1994), of the 26 samples analysed, two (totaling 7.70% of the samples) have a TOC (1.0-2.0%), eleven (42.3%) have a very high TOC (2.0-4.0%) and thirteen (50.0%) have an excellent TOC (> 4.0%) (Figure 3). An average value of 3.74% (n=15) was obtained for the RR05 samples and 5.25% (n=11) for the RR09 samples. These results agree with those presented by Souza et al. (2021) and Góes et al. (2022), who obtained TOC values between 0.11-6.29% and 1.42% - 5.6%, respectively.

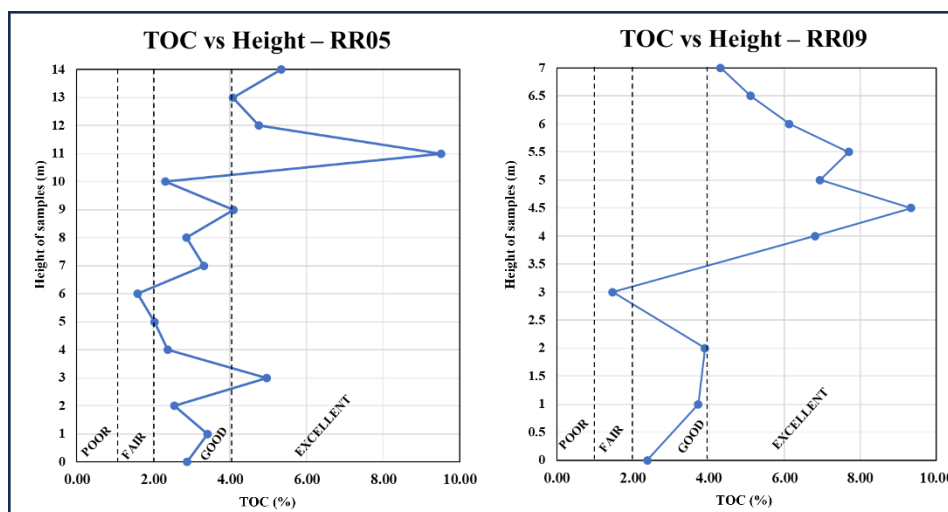


Figure 3 – Diagram with TOC vs. height of samples from the Barreirinha Formation, southern edge, Amazonas Basin. Source: Adapted from Peters & Cassa (1994).

The Rock-Eval pyrolysis results showed low values of free hydrocarbons (S1 < 0.5 mg HC/g rock), which indicates that there was little natural generation of hydrocarbons. The generating potential (S2) ranged from 3.92 to 33.98 mg HC/g rock. According to Peters and Cassa (1994), 26 samples were classified according to their hydrocarbon generation potential (S2), three (11.5%) have a moderate potential (2-5 mg HC/g rock), eight (30.8%) have a good potential (5-10 mg HC/g rock) and fifteen (57.7%) have an excellent generating potential (>10 mg HC/g rock) (Figure 4). An average value of 11.98 mg HC/g rock (n=15) was obtained for the RR05 samples, and an average value of 18.16 mg HC/g rock (n=11) was obtained for the RR09 samples. Figure 4 shows a strong correlation between the TOC and S2 values, such that the higher the TOC value is, the higher the S2 value. This same relationship was noted in other works related to the Barreirinha Formation, such as Gárcia (2014), Calderón (2017) and Góes et al. (2022).

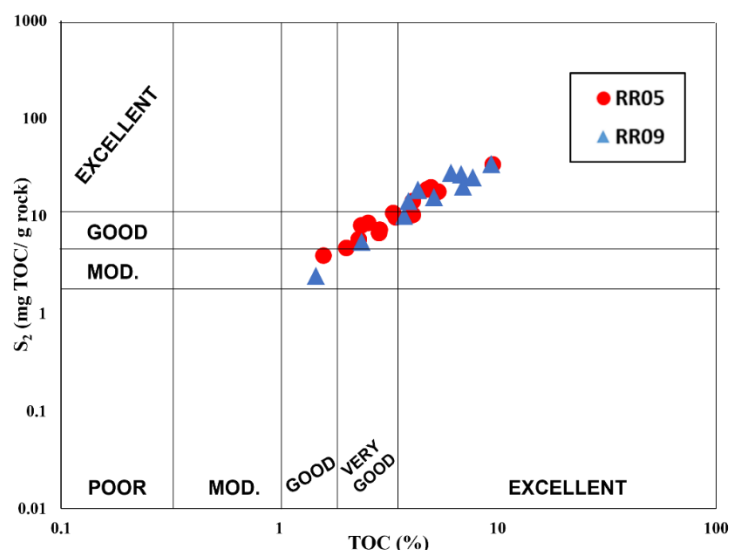


Figure 4 – Classification of the generating potential as a function of the S<sub>2</sub> versus TOC ratio of the samples from the Barreirinha Formation, Amazonas Basin. Source: Adapted from Peters & Cassa (1994).

The maximum temperature (T<sub>max</sub>) values were used to assess the thermal maturity of the samples. For this parameter, all samples showed values below 440 °C (421 °C to 430 °C), indicating thermal immaturity according to Tissot & Welte (1984) (Figure 5). This thermal immaturity exhibited by the samples is in line with several studies of different outcrops in the Barreirinha Formation at the southern edge of the Amazonas Basin (Calderón, 2017; Souza *et al.*, 2021; Góes *et al.*, 2022).

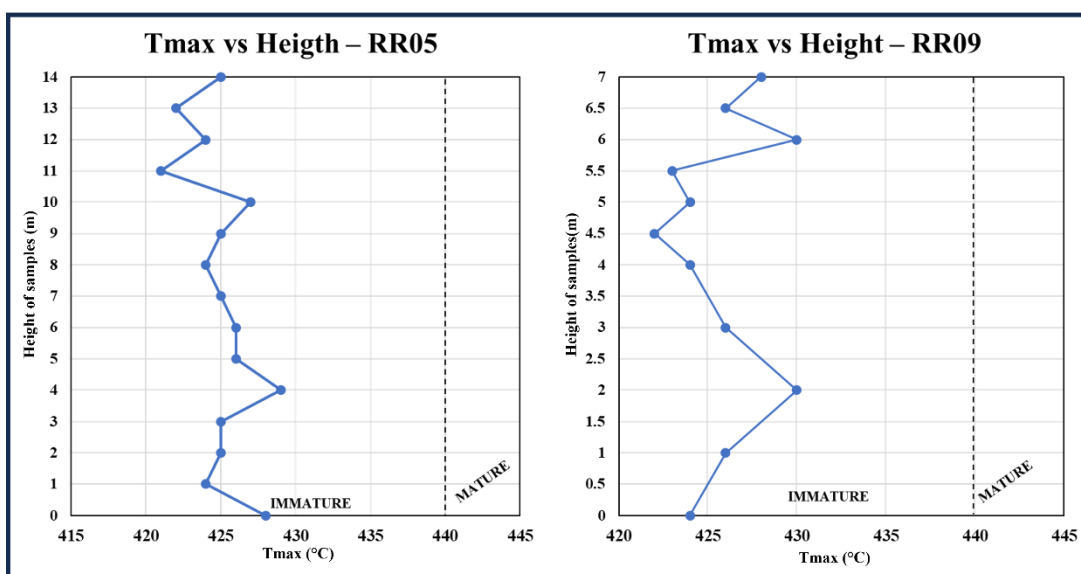


Figure 5 – Diagram with the values of T<sub>max</sub> vs. Height of samples from the Barreirinha Formation, southern edge, Amazonas Basin. Source: Adapted from Peters & Cassa (1994).

The HI and OI were correlated by using the Van Krevelen-type diagram (Figure 6) to qualitatively analyse the organic matter present in the samples and indirectly infer its nature (type of kerogen) and its degree of preservation. The interpretation of these diagrams (Figure 6) facilitated in the classification of the samples, demonstrating that the kerogen present in the samples was predominantly type II, with few samples containing type III kerogen (Peters & Cassa, 1994).

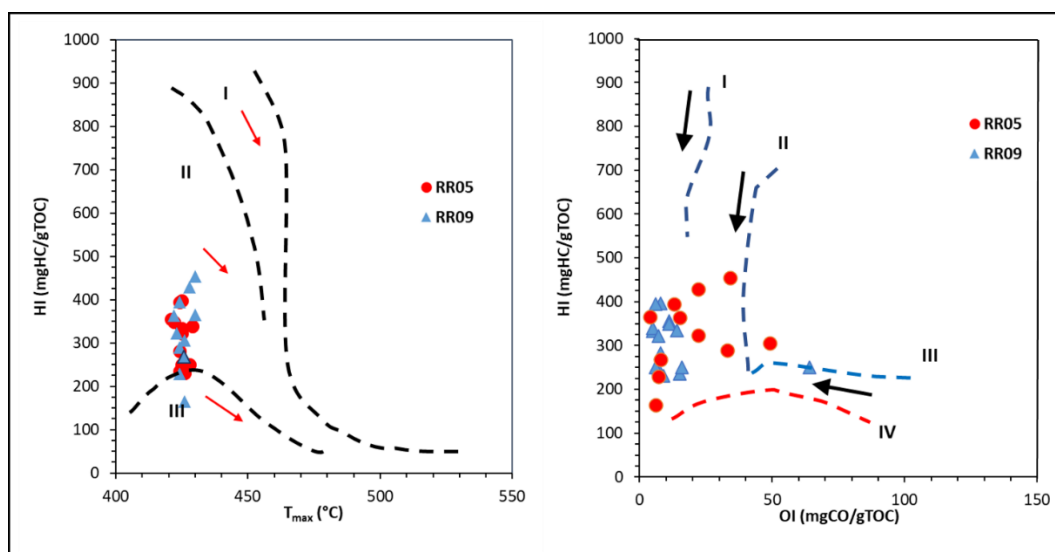


Figure 6 - Van Krevelen-type diagram showing sample distribution and kerogen types in this study. Source: Adapted from the parameters of Espitalié (1985).

### 3.2 Palynofaceis

#### 3.2.1 Organic components

The organic matter present in the samples was analyzed with palynological slides in a quantitative and qualitative way. Among the organic components, amorphous organic matter does not fluoresce, and acritarches and prasinophytes fluoresce strongly, which indicates good preservation and low thermal maturity of these components.

For the quantitative analysis, three hundred components were counted on each slide and were classified and synthesized into the three main groups of organic matter and their subgroups - palynomorphs (spores, acritarches, prasinophytes and zoomorphs), phytoclasts (opaque and non-opaque) and amorphous organic matter (AOM), as shown in Table 2. The levels of AOM obtained in the 26 analyzed samples ranged from 9% to 75%, those of phytoclasts ranged from 0 to 10% and those of palynomorphs ranged from 32% to 81%.

Table 2 - Percentages of the main groups of organic matter obtained from the analysis of palynofaciological slides of samples from the outcrops of the Barreirinha Formation.

Samples	AOM	Phytoclasts			Palynomorphs				
		Opaque	Non-Opaque	Total	Miospores	Acritarches	Prasinophytes	Zoomorphs	Total
RR 05-213	9%	5%	5%	10%	4%	33%	40%	4%	81%
RR 05-214	33%	1%	4%	5%	1%	16%	37%	9%	62%
RR 05-215	48%	1%	1%	1%	1%	11%	38%	1%	51%
RR 05-216	39%	1%	0%	1%	9%	10%	31%	10%	60%
RR 05-217	25%	1%	0%	1%	6%	8%	56%	4%	74%
RR 05-218	27%	0%	0%	0%	31%	9%	30%	4%	73%
RR 05-219	30%	0%	0%	0%	2%	12%	43%	13%	70%
RR 05-220	48%	0%	1%	1%	1%	7%	31%	11%	51%
RR 05-221	39%	0%	0%	0%	18%	17%	17%	8%	61%
RR 05-222	50%	0%	1%	1%	16%	12%	17%	5%	49%
RR 05-223	35%	0%	1%	1%	6%	13%	34%	11%	64%
RR 05-224	68%	0%	0%	0%	2%	11%	17%	3%	32%

RR 05-225	<b>48%</b>	0%	0%	<b>1%</b>	7%	27%	16%	1%	<b>51%</b>
RR 05-226	<b>33%</b>	1%	1%	<b>1%</b>	3%	20%	35%	9%	<b>66%</b>
RR 05-227	<b>55%</b>	0%	0%	<b>0%</b>	3%	20%	20%	2%	<b>45%</b>
RR09-278	<b>23%</b>	0%	0%	<b>0%</b>	0%	13%	49%	14%	<b>77%</b>
RR09-279	<b>47%</b>	0%	0%	<b>0%</b>	2%	18%	20%	13%	<b>53%</b>
RR09-280	<b>46%</b>	0%	0%	<b>0%</b>	9%	19%	17%	9%	<b>54%</b>
RR09-281	<b>28%</b>	1%	1%	<b>2%</b>	3%	28%	33%	6%	<b>70%</b>
RR09-282	<b>74%</b>	0%	0%	<b>0%</b>	1%	10%	14%	1%	<b>26%</b>
RR09-283	<b>75%</b>	0%	0%	<b>0%</b>	2%	7%	15%	1%	<b>25%</b>
RR09-284	<b>48%</b>	0%	0%	<b>0%</b>	2%	16%	20%	13%	<b>52%</b>
RR09-285	<b>50%</b>	0%	0%	<b>0%</b>	4%	20%	26%	1%	<b>50%</b>
RR09-286	<b>38%</b>	0%	0%	<b>0%</b>	1%	22%	37%	2%	<b>62%</b>
RR09-287	<b>32%</b>	1%	0%	<b>1%</b>	2%	24%	41%	1%	<b>68%</b>
RR09-288	<b>31%</b>	0%	0%	<b>0%</b>	1%	44%	23%	1%	<b>69%</b>

*Source: author (2026).*

From the qualitative and quantitative analysis of kerogen, it was possible to characterize the samples from each outcrop. Palynomorphs and amorphous organic matter (AOM) are predominant in both outcrops (Figure 7), but their relative proportions vary within the sequences studied. Phytoclasts appear the least. The predominance of amorphous organic matter and palynomorphs in relation to phytoclasts was also evidenced in the work by Goês et al. (2022), which was similarly conducted on the southern edge of the Barreirinha Formation. In the figure, it is possible to identify an inverse relationship between AOM and palynomorphs in the two groups of samples (RR05 and RR09), as one parameter increases the other decreases in a similar proportion. A very strong inverse correlation (-0.992) was obtained between the counts of AOM and of palynomorphs, suggesting that the AOM can be formed, primarily, by the degradation of palynomorphs.

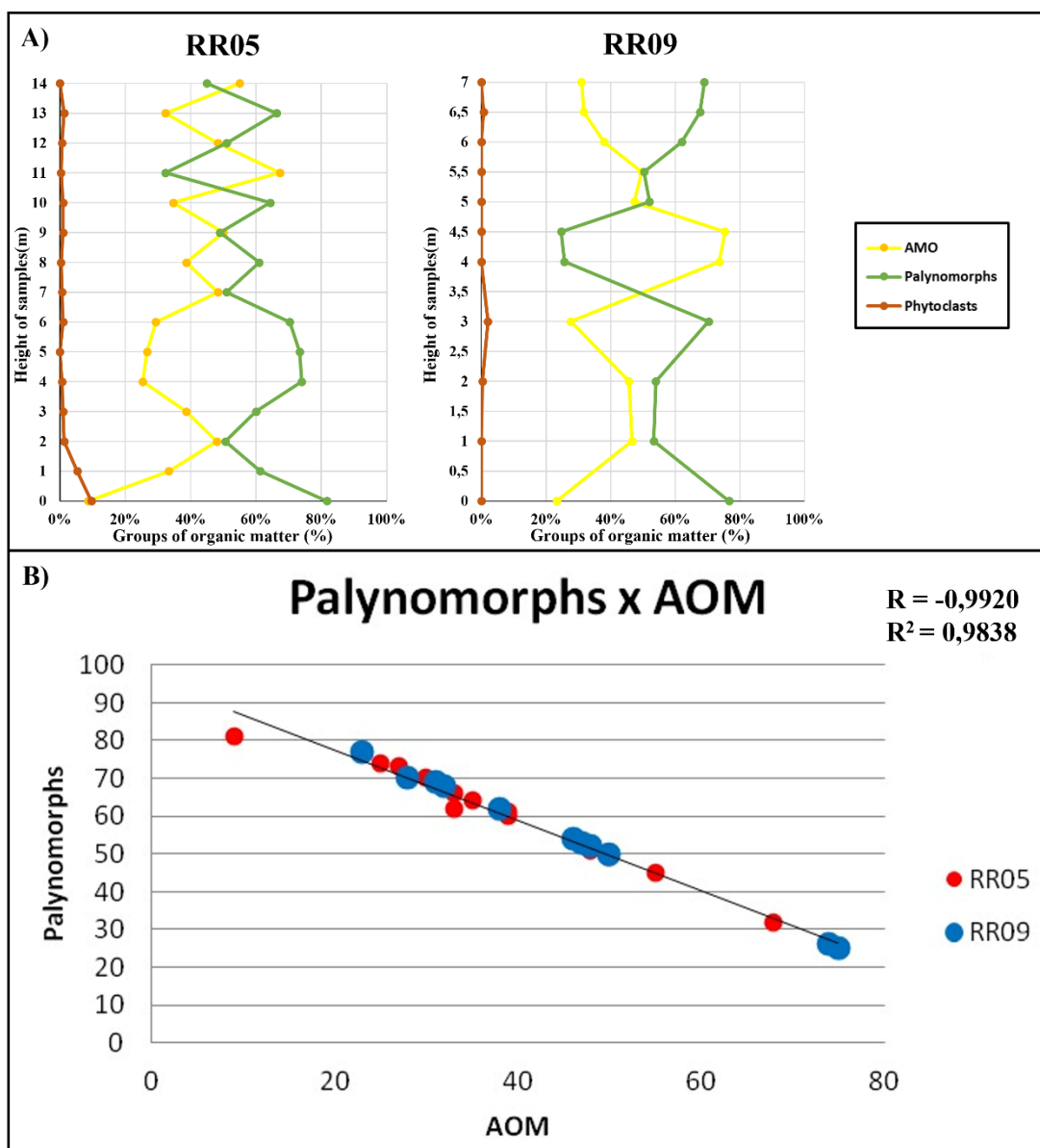


Figure 7 – A) Graph showing the distribution of the three main groups of organic matter (AOM, palynomorphs, phytoclasts) along the outcrops of the Barreirinha Formation, Amazonas Basin. B) Graph showing the correlation between palynomorphs and AOM. Source: Author (2026).

A principal component analysis (PCA; Figure 8) was performed on the AOM, palynomorph and phytoclast data. PC1 (X axis) and PC2 (Y axis) totaled 99.99% of the variance; that is, 99.99% of the data are explained by these two components. These results show that there are two principal groups: those that have considerable levels of AOM and those that have considerable levels of palynomorphs. Of the 26 samples analyzed, twelve samples (six from each outcrop) had the greatest AOM abundances. For the palynomorphs, seven samples from RR05 and five from RR09 showed substantial abundance. There were only 2 samples that had significant phytoclast abundances, RR05-213 and RR05-214, which appear ungrouped in Figure 8.

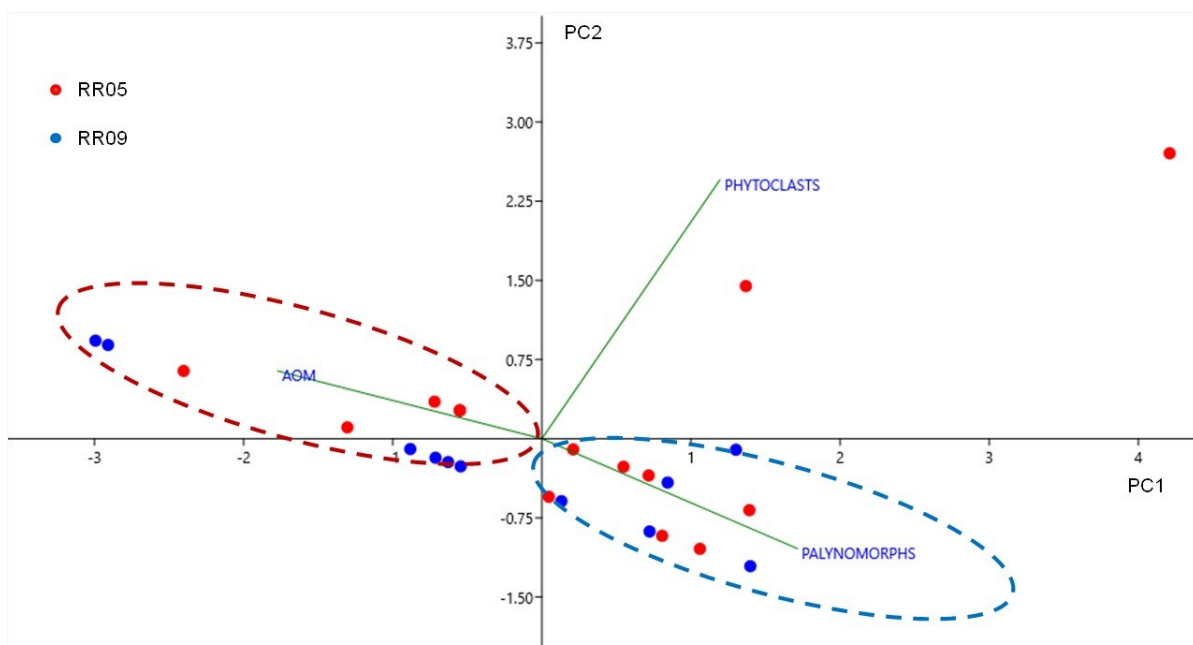


Figure 8 – PCA of the three main groups of organic matter (AOM, palynomorphs and phytoclasts) along the outcrops of the Barreirinha Formation, Amazonas Basin.

Source: Author (2026).

Phytoclasts occur in small proportions. Opaque phytoclasts are characterized by elongated, equidimensional or corroded shapes. Non-opaque phytoclasts, instead, occur mostly in a degraded form and with cuticles and lack fluorescence (Figure 9).

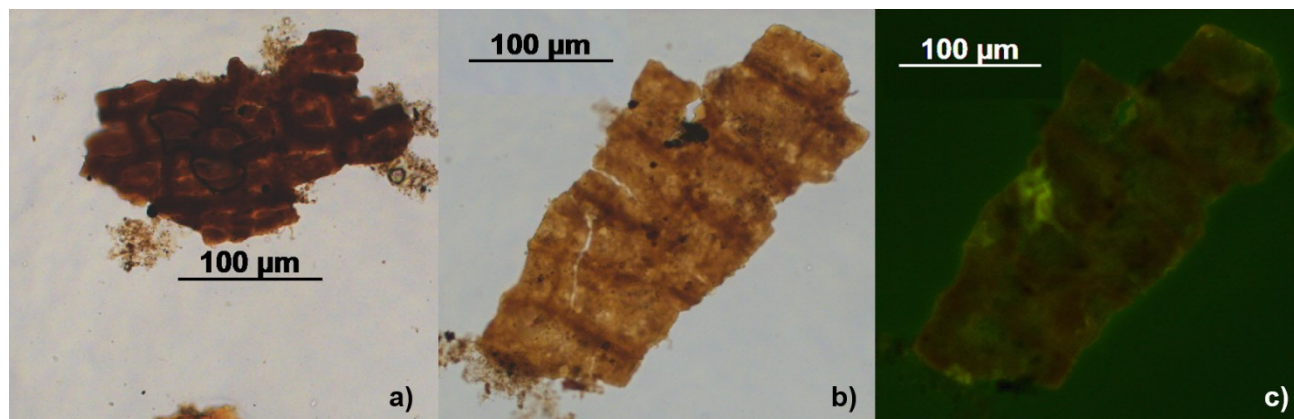


Figure 9 – Photomicrograph of different cuticles; (a) and (b) cuticles in white light; (c) cuticle in fluorescent light.

Source: Author (2026).

Amorphous organic matter (AOM) occurs in lumps or agglomerates of formless organic matter, are various shades of brown in colour, and show little or no fluorescence under UV light (Figure 10).

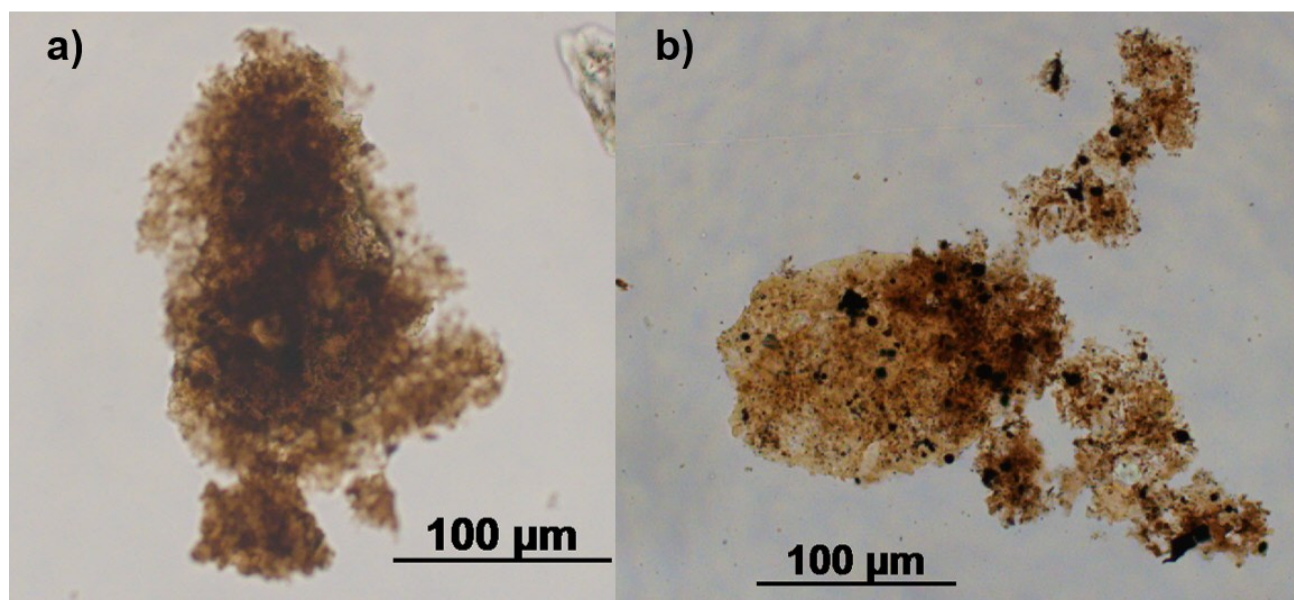


Figure 10 – Photomicrograph of amorphous organic matter found in the samples. (a) Agglomerated and darker coloured amorphous organic matter. (b) Lightly coloured amorphous organic matter.

Source: Author (2026).

The palynomorphs are mainly represented by large amounts of marine microplankton (acritarches and prasinophytes) and low amounts of terrestrial components (spores). Prasinophytes occur in large proportions on the slides and are characterized by moderate and intense fluorescence (ranging from green to yellow; Figure 11). Of the genera identified, *Pterospermella*, *Cymatiosphaera*, *Leiosperidia*, *Tasmanites*, and *Maranhites*, the latter were the most common. The acritarches occur in different proportions on the slides and are light to transparent in white light with intense (greenish - yellowish) fluorescence. This palynological association has previously been found in other works from the Amazonas Basin (Calderón, 2017; Góes *et al.*, 2022) and in works from other Devonian Basins (Andrade *et al.*, 2019; Gonzalés *et al.*, 2020). It is also worth noting that this association, composed of a wide variety of Acritarch's and Prasinophytes, is dated by several authors to the Middle to Upper Devonian range and from a predominantly marine paleoenvironment (Grahn, 1992; Grahn *et al.*, 2000; Filipiak, 2002; Grahn and de Melo, 2004; Trindade *et al.*, 2015; Trindade and Carvalho, 2018; Andrade *et al.*, 2019; Gonzalés *et al.*, 2020a; Gonzalés *et al.*, 2020b).

According to standard palynofacies and fluorescence scales, the observed fluorescence colors (greenish - yellowish) also indicate a low to moderate level of thermal maturity, consistent with immature to early mature stages of hydrocarbon generation within the basin. This interpretation is further supported by the low estimated  $T_{max}$  obtained from Rock-Eval pyrolysis analyses of the samples.

The spores occur with different colourations, ranging from light brown to dark brown, with different shapes and ornamentations. Most occur in clusters or in small proportions. These spores are mostly related to bryophytes and pteridophytes from a wide variety of genera, though the genera *Geminospora*, *Samarisporites*, and *Grandispora* are the most pronounced. This group has little or no fluorescence, as shown in Figure 11.

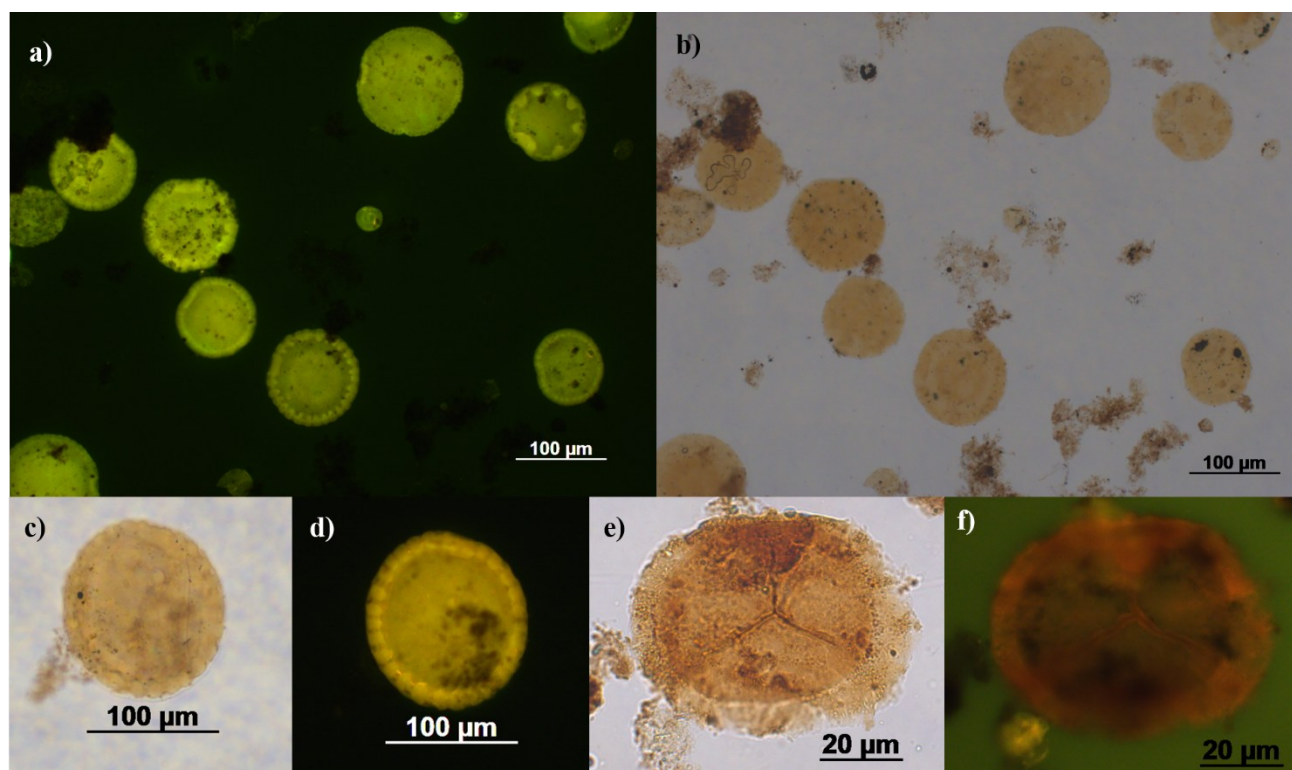


Figure 11 – Photomicrographs showing the main representatives of the palynomorph group in the samples. The occurrence of several prasinophytes from part of the RR05-218 sample slide are shown in fluorescent (a) and normal light (b) Image of the RR05-215 sample slide, highlighting a prasinophyte of the genus *maranhites* in white (c) and fluorescent light (d); Image of sample RR09-279 slide, highlighting a spore with triletes in white (e) and fluorescent light (f).

Source: Author (2026).

In terms of marine and terrestrial components, the analyses of both outcrops show that there is a predominance of marine components in relation to terrestrial components. In the RR05 outcrop there are instances indicating an increase in terrestrial components (spores and phytoclasts) and a decrease in marine components (prasinophytes and acritarches), and vice versa. These fluctuations likely reflect the transgressive/regressive cycles that occurred in the basin during organic matter deposition, as shown in Figure 12.

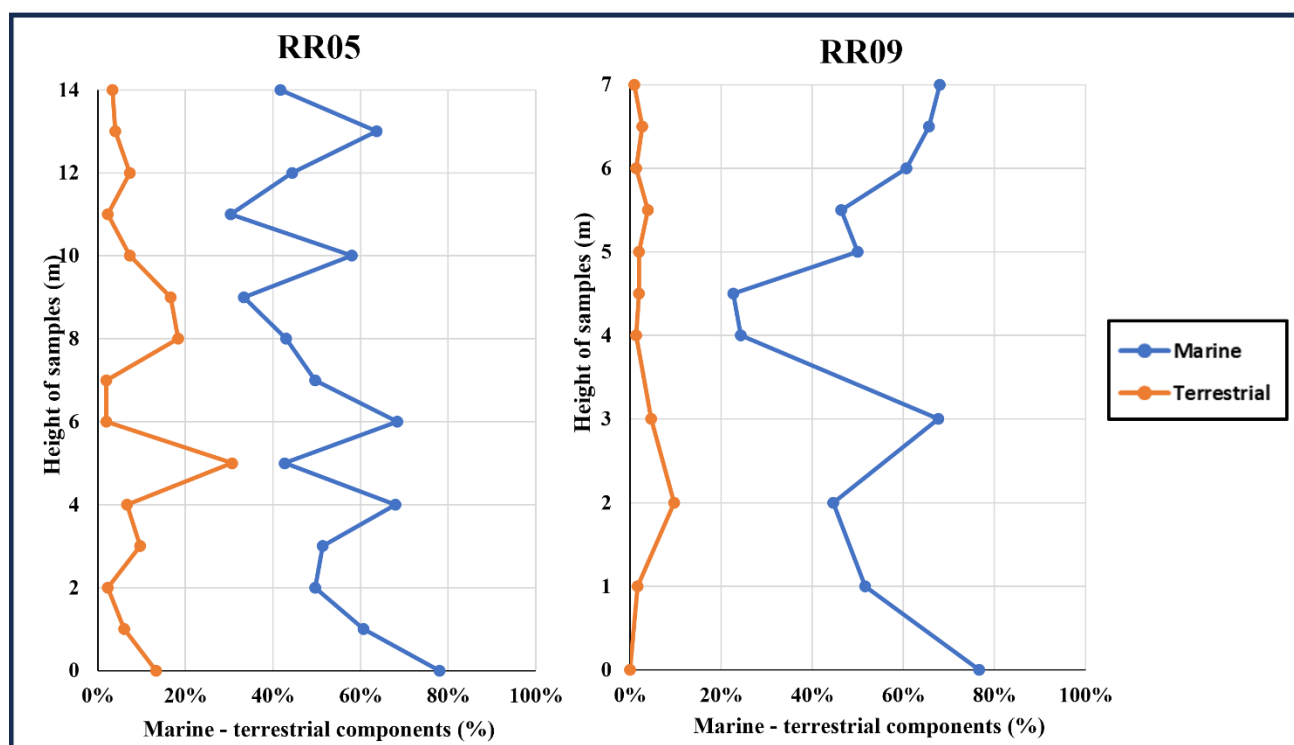


Figure 12- Graphs showing the variation in marine and terrestrial components along the outcrops of the Barreirinha Formation, Amazon Basin.  
Source: Author (2026).

### 3.2.2 Cluster analysis and palynofacies

The application of cluster analysis in Q-mode in the counting data of the organic components of the samples organized the samples into two main groups with different amounts of organic components, which allowed for the two main palynofacies associations to be defined, palynofacies I (PAL-I) and palynofacies II (PAL-II), as shown in Figure 13. Two-way analysis of organic components was also performed, which allowed classifying organic components by their similarity to each other, as shown in Figure 13.

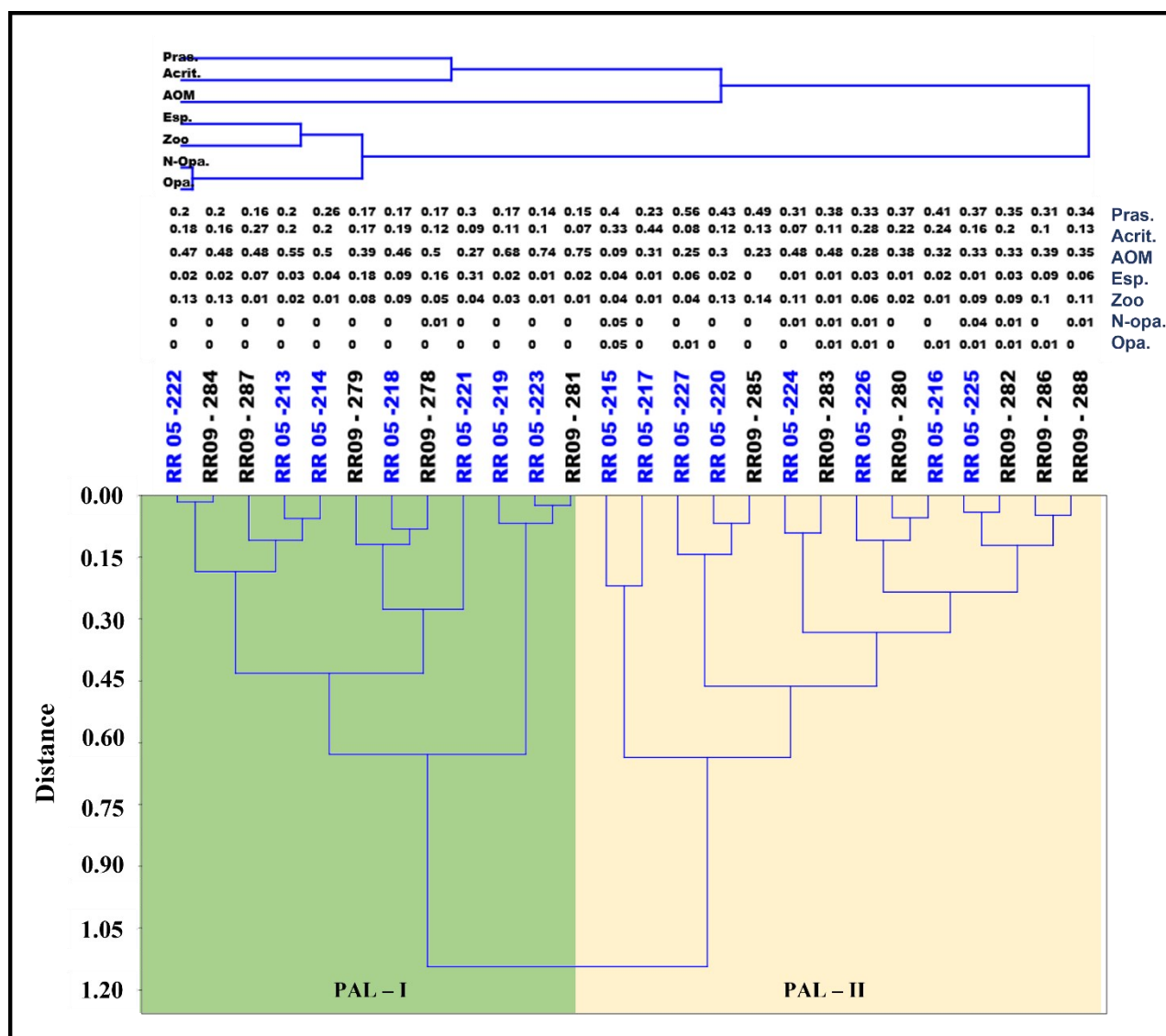


Figure 13 - Cluster analysis in Q-mode and two-way mode of samples from the Barreirinha Formation. PAL-I: Palynofacies I Association; PAL-II: Palynofacies II Association. Source: Author (2026).

Palynofacies I consist of samples that have a high AOM content, ranging from 38 to 75%, intermediate levels of marine palynomorphs (Prasinophytes and acritarches), and contributions of marine zoomorphs (chitinozoans and scholecondons). In addition, there is a low amount of terrestrial palynomorphs (spores) and no significant amounts of phytoclasts (opaque and non-opaque). This association occurs in some portions of the studied sections and is represented by samples RR05–216, RR05–224, RR05–225, RR05–227, and RR09–282 to RR09–287.

Palynofacies II is composed of samples with higher contributions of terrestrial (spores) and marine palynomorphs (acritarches and prasinophytes), varied AOM contents significantly below those in PAL-I, and phytoclasts (opaque and non-opaque) that, despite being subordinate, are the largest of the sequences studied. This palynofacies is characterized by high levels of marine palynomorphs; acritarches occur in all samples with levels ranging from 8 to 44%, and prasinophytes are the largest representatives of these samples, with minimum values of 16% and maximum values of 56%. This association occurs in samples RR05–213, RR05–214, RR05–215, RR05–217 to RR05–223, RR05–226, RR09–278 to RR09–281, and RR09–288.

### 3.2.3 Organic matter and depositional paleoenvironment

From the analysis of the organic components, their proportions and the palynofacies generated, it is possible to affirm that the samples from both outcrops were deposited in a predominantly marine environment that contained terrestrial contributions. In addition, the identified palynofacies correspond to two distinct stratigraphic intervals marking moments of sea level oscillation during the deposition of shales within the Barreirinha Formation. This hypothesis is supported by the insertion of samples in ternary diagrams that make inferences about the depositional paleoenvironment (Tyson, 1995; Souza *et al.*, 2007), as seen in Figure 14.

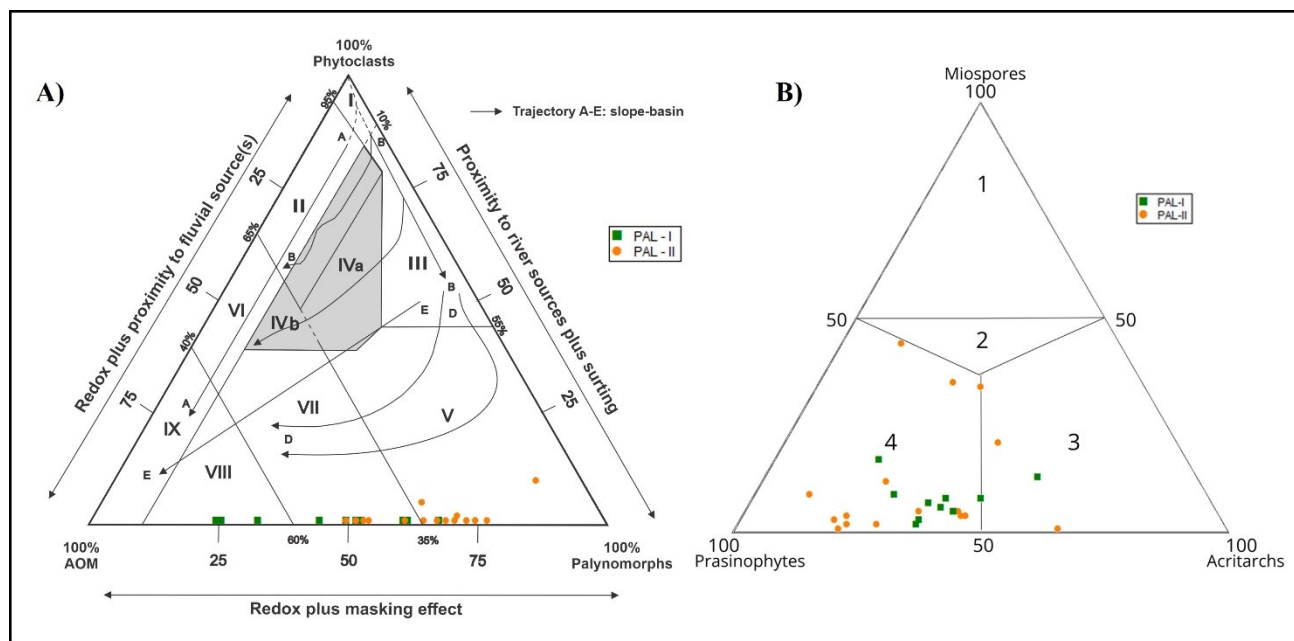


Figure 14 - Samples corresponding to each palynofacies and plotted in A- Tyson's Diagram (1995), showing inferences made about the depositional paleoenvironment I- highly proximal shelf or basin, II- marginal dysoxic-anoxic basin, III- heterolithic oxic shelf (proximal shelf), IV- shelf to basin transition, V- mud-dominated oxic shelf (distal shelf), VI- proximal suboxic-anoxic shelf, VII- distal dysoxic-anoxic "shelf", VIII- distal dysoxic-oxic shelf, and IX- proximal suboxic-anoxic basin. B- Ternary diagram adapted from Souza, 2007: 1- proximal shelf oxic (fluvial-deltaic influence), 2- proximal-distal oxic shelf (fluvial-deltaic influence?), 3- distal oxic-dysoxic shelf, 4- distal dysoxic-anoxic shelf/basin.

Stratigraphic interval I associated with palynofacies I is mainly characterized by a predominance of AOM, the occurrence of marine zoomorphs and a low contribution of terrestrial components (phytoclasts and spores). Samples associated with this range have the highest TOC contents of both sections (4.75 to 9.5%). For this interval, Tyson's diagram (1995) indicates two main fields, VII - distal dysoxic-anoxic shelf and VIII - distal dysoxic-oxic shelf. The ternary diagram of the palynomorph group proposed by Souza *et al.* (2007) predominantly indicates a distal dysoxic-anoxic shelf/basin (field 4), with a sample associated with the distal oxic-dysoxic shelf (field 3).

Stratigraphic interval II associated with palynofacies II is characterized by the predominance of marine palynomorphs (prasinophytes and acritarches), intermediate contributions of terrestrial components (spores and phytoclasts) and a varied contribution of amorphous organic matter. Samples in this range have TOC contents ranging from intermediate to high (1.47 to 4.31%). Samples from this range were deposited in a mud-dominated oxic shelf (distal shelf) (field V) and distal dysoxic-anoxic shelf (field VII) (Tyson, 1995). In the ternary diagram of palynomorphs (Figure 14B), the samples also plot in fields 3 and 4 (indicating a distal platform with oxic-dysoxic-anoxic variation), but due to the greater contribution of spores, some samples fall closer to the boundary of field 2 (proximal-distal oxic shelf (fluvial-deltaic influence)). A higher contribution of spores in some samples suggests a greater terrestrial influence, indicative of a more proximal setting within the shelf, possibly influenced by fluvial or deltaic input (Figure 14).

### 3.2.4 Pearson's Correlation Coefficient Analysis

Pearson's correlation coefficient ( $r$ ) measures the degree of linear correlation between two variables (Moore, 2007; Garson, 2009). Its values range from -1 to 1, where a perfect positive correlation is indicated by the value 1, a perfect negative correlation is represented by -1 and the absence of a linear correlation between the variables is indicated by 0 (Kozak, 2009).

Applying the Pearson coefficient correlation to the Rock-Eval pyrolysis variables and in the organic components, it was possible to establish a linear correlation between them, as shown in Table 3.

Table 3 - Pearson's correlation coefficient (*r*) between Rock Eval pyrolysis parameters and organic components of the samples studied.

	AOM	Opaque phytoclasts	Non opaque phytoclasts	Miospores	Acritarches	Prasinophytes	Zoomorphs	TOC	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	HI	OI
AOM	1												
Opaque phytoclasts	-0.538	1											
Non opaque phytoclasts	-0.423	0.787	1										
Miospores	-0.160	-0.103	-0.117	1									
Acritarches	-0.395	0.337	0.230	-0.199	1								
Prasinophytes	-0.737	0.409	0.277	-0.189	-0.052	1							
Zoomorphs	-0.298	-0.105	0.059	-0.034	-0.277	0.210	1						
TOC	0.754	-0.248	-0.287	-0.273	-0.088	-0.557	-0.417	1					
S <sub>1</sub>	0.746	-0.258	-0.224	-0.272	-0.228	-0.473	-0.358	0.873	1				
S <sub>2</sub>	0.730	-0.260	-0.328	-0.307	-0.035	-0.513	-0.487	0.965	0.850	1			
S <sub>3</sub>	0.118	-0.078	0.072	0.3018	-0.103	-0.220	-0.068	0.010	-0.148	-0.065	1		
HI	0.425	-0.187	-0.299	-0.305	0.116	-0.242	-0.460	0.568	0.500	0.739	-0.168	1	
OI	-0.271	0.601	0.375	-0.136	0.486	0.102	-0.287	0.223	0.036	0.174	0.058	0.038	1

Source: Author (2026).

Analysing the Pearson correlation coefficients obtained between the parameters, a very strong positive correlation between the TOC and S<sub>2</sub> values is evident. This indicates a strong dependence of hydrocarbon generation on TOC content and is corroborated by strong correlations between TOC and S<sub>1</sub>, and S<sub>1</sub> and S<sub>2</sub>. The strong positive correlation between HI and the S<sub>2</sub> index indicates that samples with higher HI values contain higher-quality organic matter. Furthermore, in the samples studied here, the free hydrocarbons (S<sub>1</sub>) and the generating potential (S<sub>2</sub>) have a strong positive correlation as well as a strong correlation with the HI thus confirming the higher the amount of hydrogen present in the organic matter, the greater the generating potential of the samples.

The strong correlations between the AOM with the values of TOC, S<sub>1</sub> and S<sub>2</sub> suggest that the organic material that generates hydrocarbons has amorphous organic matter as one of the main sources. On the other hand, the levels of AOM and palynomorphs show a very strong inverse correlation (-0.992), suggesting that AOM may be derived from degradation of palynomorphs. This can be confirmed by the variations in AOM and palynomorphs in the two groups of samples (RR05 and RR09), as visualized in Figure 7. Palynomorphs are subdivided into miospores, acritarches, prasinophytes and zoomorphs. All showed negative correlations with AOM. Among them prasinophytes was the one that exerted the most influence on the final correlation, showing a strong inverse correlation (-0.737). Furthermore, it was found that there is a strong positive correlation between opaque and non-opaque phytoclasts as both indicate a greater continental contribution.

#### 4. Conclusions

All samples from the studied outcrops (RR05 and RR09) show high to excellent TOC contents, moderate to excellent hydrocarbon generation potential (S<sub>2</sub>), with predominantly type II kerogen. The samples also exhibit low thermal maturity (T<sub>max</sub> <440 °C), further supported by the fluorescence coloration (greenish-yellowish) of the prasinophytes and acritarches.

Quantitative palynofacies analysis of the main organic components of organic matter demonstrated the presence and abundance of amorphous organic matter (AOM) and palynomorphs and subordinate amounts of phytoclasts. Furthermore, the samples showed a predominance of marine components (acritarches and prasinophytes) over terrestrial components (miospores and phytoclasts), reflecting deposition under marine-dominated conditions.

Multivariate statistics proved to be efficient for data interpretation and correlation. Principal components analysis (PCA) indicated a predominance of two main groups, one related to greater significance of AOM and the other to greater significance of palynomorphs.

The cluster analysis defined two palynofacies, named PAL-I and PAL-II, which are related to two distinct stratigraphic intervals driven by sea level oscillations associated with transgressive/regressive cycles within the basin. The samples from PAL-I mainly have a high concentration of AOM, and those from PAL II have a greater contribution of marine and terrestrial palynomorphs.

The characteristics of the organic components and the palynofacies generated indicate that the samples studied were deposited in a predominantly marine environment with different levels of terrestrial contributions along the outcrops. The depositional paleoenvironment of the samples was classified as a distal dysoxic-anoxic platform for the palynofacies I samples and an oxid-dysoxic

distal platform for the palynofacies II samples. These conditions also suggest variations in organic matter preservation, with better preservation of AOM under more reducing conditions and partial degradation of palynomorphs in relatively more oxygenated intervals.

Pearson's correlation coefficients obtained between Rock-Eval pyrolysis parameters and organic components show that there is a strong correlation between AOM and TOC and S1 and S2 values, which indicates that amorphous organic matter is one of the main sources of organic material that generates hydrocarbons. There is also a strong negative correlation between the levels of AOM and palynomorphs, confirming that AOM can be formed by the degradation of palynomorphs.

Overall, the integration of organic geochemical parameters and palynofacies analysis enabled a detailed characterization of the quality, type, and preservation of organic matter, as well as its paleoenvironmental context. These results highlight not only the predominantly marine depositional setting influenced by sea-level fluctuations but also reinforce the hydrocarbon generation potential of the studied succession within the Amazonas Basin.

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### References

- ANDRADE, C. L. N.; CARDOSO, T. R. M.; SANTOS, R. R.; DINO, R.; MACHADO, A. J. Organic facies and palynology from the middle to late Devonian of the Pimenteiras Formation, Parnaíba Basin, Brazil. *Journal of South American Earth Sciences*, v. 99, 2019. Disponível em: <https://doi.org/10.1016/j.jsames.2019.102481>.
- CALDERÓN, S. M. *Geoquímica orgânica da Formação Barreirinha, Devoniano Superior da Bacia do Amazonas, município de Rurópolis, PA: implicações paleoambientais e avaliação do potencial gerador de hidrocarbonetos*. Dissertação (Mestrado em Geologia e Geoquímica) – Instituto de Geociências, Universidade Federal do Pará, Belém, 2017. Disponível em: <http://repositorio.ufpa.br:8080/jspui/handle/2011/9431>.
- CAPUTO, M. V. *Stratigraphy, tectonics, paleoclimatology and paleogeography of northern basins of Brazil*. 1984. Tese (Doutorado) – University of California, California, 1984. Disponível em: [http://repositorio.ufpa.br/jspui/bitstream/2011/8961/6/Tese\\_StratigraphyTectonicsPaleoclimatology.pdf](http://repositorio.ufpa.br/jspui/bitstream/2011/8961/6/Tese_StratigraphyTectonicsPaleoclimatology.pdf).
- CAPUTO, M. V.; SOARES, E. A. A. Eustatic and tectonic change effects in the reversion of the transcontinental Amazon River drainage system. *Brazilian Journal of Geology*, v. 46, n. 2, p. 301–328, 2016. Disponível em: <https://doi.org/10.1590/2317-4889201620160066>.
- CPRM – COMPANHIA DE PESQUISA DE RECURSOS MINERAIS. *GeoSGB – dados, informações e produtos do Serviço Geológico do Brasil*. 2006. Disponível em: <http://geosgb.cprm.gov.br>.
- CORRAR, L. J.; PAULO, E.; DIAS FILHO, J. M. *Análise multivariada: para os cursos de administração, ciências contábeis e economia*. São Paulo: Atlas, 2007. 541 p.
- CUNHA, P. R. C. *Análise estratigráfica dos sedimentos eo/mesodevonianos da porção ocidental da Bacia do Amazonas sob a ótica da estratigrafia de seqüências no interior cratônico*. 2000. Dissertação (Mestrado) – Faculdade de Geologia, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2000. Disponível em: <https://lume.ufrgs.br/bitstream/handle/10183/2657/000323981.pdf>.
- CUNHA, P. R. C.; GONZAGA, F. G.; COUTINHO, L. F. C.; FEIJÓ, F. J. Bacia do Amazonas. *Boletim de Geociências da Petrobras*, v. 8, n. 1, p. 47–55, 1994.
- CUNHA, P. R. C.; MELO, J. M.; SILVA, O. Bacia do Amazonas. *Boletim de Geociências da Petrobras*, v. 15, n. 2, p. 227–251, 2007.
- ESPITALIÉ, J.; LAPORTE, J. L.; MADEC, M.; MARQUIS, F.; LEPAT, P.; PAULET, J.; BOUTEFEU, A. Méthode rapide de caractérisation des roches mère, de leur potentiel pétrolier et de leur degré d'évolution. *Revue de l'Institut Français du Pétrole*, v. 32, p. 23–42, 1977. Disponível em: <https://doi.org/10.2516/ogst:1977002>.

FERREIRA, A.; RIGUETI, A.; BASTOS, G. *Bacia do Amazonas*. Manaus: Superintendência de Definição de Blocos SDB – ANP, 2015. 14 p. Disponível em: [http://rodadas.anp.gov.br/arquivos/Round\\_13/areas\\_oferecidas\\_r13/Sumarios\\_Geologicos/Sumario\\_Geologico\\_Bacia\\_Amazonas\\_R13.pdf](http://rodadas.anp.gov.br/arquivos/Round_13/areas_oferecidas_r13/Sumarios_Geologicos/Sumario_Geologico_Bacia_Amazonas_R13.pdf).

GARCIA, P. H. *Geoquímica orgânica das Formações Ererê, Barreirinha e Curiri (meso e neo devoniano) em dois poços na porção oeste da Bacia do Amazonas*. 2014. Dissertação (Mestrado) – Programa de Pós-Graduação em Análise de Bacias e Faixas Móveis, Faculdade de Geologia, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, 2014. 81 p.

GARSON, G. D. *Statnotes: topics in multivariate analysis*. 2009. Disponível em: <http://faculty.chass.ncsu.edu/garson/PA765/statnote.html>.

GÓES, V. C. M.; COSTA, A. B.; CERQUEIRA, J. R.; ABREU, N. C.; SILVA, A. S.; MIRANDA, F. L. C.; QUEIROZ, A. F. S.; RIBEIRO, H. J. P. S. Potencial gerador e maturidade térmica dos folhelhos da Formação Barreirinha, borda sul da Bacia do Amazonas, Brasil. *Geologia USP Série Científica*, v. 21, n. 3, p. 3–17, 2021. Disponível em: <https://doi.org/10.11606/issn.2316-9095.v21-171844>.

GÓES, V. C. M.; COSTA, A. B.; ANDRADE, C. L. N.; CERQUEIRA, J. R.; SILVA, A. S.; GARCIA, K. S.; QUEIROZ, A. F. S.; RIBEIRO, H. J. P. S.; DINO, R. Hydrocarbon source potential and paleodepositional environment of the Devonian Barreirinha Formation on the south edge of the Amazonas Basin, Brazil. *Journal of South American Earth Sciences*, v. 115, 2022. Disponível em: <https://doi.org/10.1016/j.jsames.2022.103722>.

GONZÁLES, L. D. C.; MASTALERZ, M.; MENDONÇA FILHO, J. G. Application of organic facies and biomarkers in characterization of paleoenvironmental conditions and maturity of sediments from the Codó Formation in the west-central part of the São Luís Basin, Brazil. *International Journal of Coal Geology*, v. 225, 2020b. Disponível em: <https://doi.org/10.1016/j.coal.2020.103482>.

GONZÁLES, L. D. C.; MENDONÇA FILHO, J. G.; MASTALERZ, M. Depositional environment and maturity of Devonian Pimenteira Formation in the São Luís Basin, Brazil. *International Journal of Coal Geology*, v. 221, 2020a. Disponível em: <https://doi.org/10.1016/j.coal.2020.103429>.

GRAHN, Y. Ordovician chitinozoa and biostratigraphy of Brazil. *Geobios*, v. 25, n. 6, p. 703–723, 1992. Disponível em: [https://doi.org/10.1016/S0016-6995\(92\)80052-F](https://doi.org/10.1016/S0016-6995(92)80052-F).

GRAHN, Y.; MELO, J. H. G. Integrated Middle Devonian chitinozoan and miospore zonation of the Amazonas Basin, northern Brazil. *Revue de Micropaléontologie*, v. 47, n. 2, p. 71–85, 2004. Disponível em: <https://doi.org/10.1016/j.revmic.2004.03.001>.

GRAHN, Y.; PEREIRA, E.; BERGAMASCHI, S. Silurian and Lower Devonian chitinozoan biostratigraphy of the Paraná Basin in Brazil and Paraguay. *Palynology*, v. 24, p. 143–172, 2000. Disponível em: <https://doi.org/10.1080/01916122.2000.9989542>.

KABANOV, P.; JIANG, C. Photic-zone euxinia and anoxic events in a Middle–Late Devonian shelfal sea of Panthalassan continental margin, NW Canada: changing paradigm of Devonian Ocean and sea level fluctuations. *Global and Planetary Change*, v. 188, p. 103153, 2020.

KALKREUTH, W.; HOLZ, M.; KERN, M.; MACHADO, G.; MEXIAS, A.; SILVA, M. B.; WILLETT, J.; FINKELMAN, R.; BURGER, H. Petrology and chemistry of Permian coals from the Paraná Basin: Santa Terezinha, Leão-Butiá and Candiota Coalfields, Rio Grande do Sul, Brazil. *International Journal of Coal Geology*, v. 68, p. 79–116, 2006.

KILLOPS, S.; KILLOPS, V. *Introduction to organic geochemistry*. 2. ed. Oxford: Blackwell Science, 2005. 393 p.

KILLOPS, S. D.; FREWIN, N. L. Triterpenoid diagenesis and cuticular preservation. *Organic Geochemistry*, v. 21, n. 12, p. 1193–1209, 1994. Disponível em: [https://doi.org/10.1016/0146-6380\(94\)90163-5](https://doi.org/10.1016/0146-6380(94)90163-5).

KOZAK, M. What is strong correlation? *Teaching Statistics*, v. 31, p. 85–86, 2009.

LAFARGUE, E.; MARQUIS, F.; PILLOT, D. Rock-Eval 6 applications in hydrocarbon exploration, production, and soil contamination studies. *Revue de l'Institut Français du Pétrole*, v. 53, n. 4, p. 421–437, 1998. Disponível em: <https://doi.org/10.2516/ogst:1998036>.

LOBOZIAK, S.; MELO, J. H. G.; MATSUDA, N. S.; QUADROS, L. P. Miospore biostratigraphy of the type Barreirinha Formation (Curuá Group, Upper Devonian) in the Tapajós River area, Amazon Basin, North Brazil. *Bulletin des Centres de Recherches Exploration-Production Elf Aquitaine*, v. 21, p. 187–205, 1997.

MENDONÇA FILHO, J. G.; GONÇALVES, P. A. Organic matter: concepts and definitions. In: SUÁREZ-RUIZ, I.; MENDONÇA FILHO, J. G. (org.). *Geology: current and future developments – the role of organic petrology in the exploration of conventional and unconventional hydrocarbon systems*. United Arab Emirates: Bentham Science, 2017. v. 1, p. 1–33.

MENDONÇA FILHO, J. G.; MENEZES, T. R.; MENDONÇA, J. O. Organic composition (palynofacies analysis). In: ICCP TRAINING COURSE ON DISPERSED ORGANIC MATTER, 2011, p. 33–81.

MENDONÇA FILHO, J. G.; MENEZES, T. R.; MENDONÇA, J. O.; OLIVEIRA, A. D.; CARVALHO, M. A.; SANT'ANNA, A. J.; SOUZA, J. T. Palinofácies. In: CARVALHO, I. S. (org.). *Paleontologia*. Rio de Janeiro: Interciência, 2010. v. 2, p. 379–413.

MILANI, E. J.; RANGEL, H. D.; BUENO, G. V.; STICA, J. M.; WINTER, W. R.; CAIXETA, J. M.; PESSOA NETO, O. C. Bacias sedimentares brasileiras – cartas estratigráficas. *Boletim de Geociências da Petrobras*, v. 15, p. 183–205, 2007.

MOORE, D. S. *The basic practice of statistics*. New York: Freeman, 2007.

PETERS, K. E.; CASSA, M. R. Applied source rock geochemistry. In: MAGOON, L. B.; DOW, W. G. (ed.). *The petroleum system: from source to trap*. Tulsa: American Association of Petroleum Geologists, 1994. p. 93–120.

POGGIO, C. A.; JESUS, G. C.; QUEIROZ, A. F. S.; MARTINS, C. M. S.; SILVA JUNIOR, J. B. Estudo analítico aplicado ao procedimento de isolamento do querogênio em amostras de rochas com potencial gerador de hidrocarbonetos. *Anuário do Instituto de Geociências – UFRJ*, v. 42, p. 346–354, 2019. Disponível em: [https://doi.org/10.11137/2019\\_1\\_346\\_354](https://doi.org/10.11137/2019_1_346_354).

SEDAT, I.; FARIBORZ, G.; ANDREAS, S. M.; KHALED, A.; SALMAN, Q.; OMID, H. A.; TULAY, I.; AMER, A. T. The Silurian Qusaiba hot shales of Saudi Arabia: an integrated assessment of thermal maturity. *International Journal of Coal Geology*, v. 159, p. 107–119, 2016. Disponível em: <https://doi.org/10.1016/j.coal.2016.04.004>.

SOUZA, I. M. F.; CERQUEIRA, J. R.; GARCIA, K. S.; RIBEIRO, H. J. P. S.; OLIVEIRA, O. M. C.; QUEIROZ, A. F. S.; TEIXEIRA, L. S. G. Geochemical characterization and origin of kerogens from source-rock of Devonian in the Amazonas Basin, Brazil. *Journal of South American Earth Sciences*, v. 111, 2021. Disponível em: <https://doi.org/10.1016/j.jsames.2021.103437>.

SOUZA, I. V. A. F. *Faciologia orgânica de seções devonianas da Bacia do Parnaíba (Formação Pimenteira): implicações para geração de petróleo*. 2007. Monografia – Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2007. 182 p.

SOUZA, M. S. P.; MAULLER, P. M.; CARDOSO, T. R.; RODRIGUES, R.; PEREIRA, E. Caracterização geoquímica e bioestratigráfica das superfícies de inundação marinha da seção meso-neodevoniana, na região de Dom Aquino (MT), noroeste da Bacia do Paraná, Brasil. *Anuário do Instituto de Geociências – UFRJ*, v. 36, n. 1, p. 15–25, 2013. Disponível em: [https://doi.org/10.11137/2013\\_1\\_15\\_25](https://doi.org/10.11137/2013_1_15_25).

TISSOT, B.; WELTE, D. H. *Petroleum formation and occurrence*. 2. ed. Heidelberg: Springer-Verlag, 1984. 699 p.

TRINDADE, V. S. F.; CARVALHO, M. A. Paleoenvironment reconstruction of Parnaíba Basin (north Brazil) using indicator species analysis (IndVal) of Devonian microphytoplankton. *Marine Micropaleontology*, v. 140, p. 69–80, 2018. Disponível em: <https://doi.org/10.1016/j.marmicro.2018.02.003>.

TRINDADE, V. S. F.; CARVALHO, M. A.; BORGHI, L. Palynofacies patterns of the Devonian of the Parnaíba Basin, Brazil: paleoenvironmental implications. *Journal of South American Earth Sciences*, v. 61, p. 164–175, 2015. Disponível em: <https://doi.org/10.1016/j.jsames.2015.06.001>.

TYSON, R. V. *Sedimentary organic matter: organic facies and palynofacies*. London: Chapman & Hall, 1995. 615 p.