

PALYNOLOGY OF THE AGUARDIENTE AND LOWER CAPACHO - FORMATIONS, CATATUMBO BASIN, COLOMBIA

PALINOLOGÍA DE LA PARTE BAJA DE LA FORMACIÓN CAPACHO - FORMACIÓN AGUARDIENTE, CUENCA DEL CATATUMBO, COLOMBIA

PALINOLOGIA DA PARTE BAIXA DA FORMAÇÃO CAPACHO - FORMAÇÃO AGUARDIENTE, BACIA DO CATATUMBO, COLÔMBIA

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ABSTRACT

The Catatumbo Basin is located in the North East of Colombia and is the opposite side of the Maracaibo basin in Venezuela. Although the main hydrocarbon reservoirs belong to the Cenozoic, the Cretaceous also has reported good results in oil production. The Aguardiente Formation is one of the main Cretaceous reservoirs of the basin. Key aspects of this Formation including age and depositional environment are still unclear. In this paper, we analyze the palynology of 86 samples from the Aguardiente and the Capacho Formations. Palynology suggests an Albian-Early Cenomanian age for the sequence. The Aguardiente accumulated in transitional environments while the Capacho accumulated in shallow marine environments.

Keywords: *Catatumbo basin Colombia, Cretaceous, Palynology, Capacho Formation, Aguardiente Formation.*

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RESUMEN

La cuenca del Catatumbo se encuentra localizada en la parte nororiental de Colombia y es la contraparte de la cuenca de Maracaibo en Venezuela. Los principales reservorios se encuentran en la secuencia Cenozoica. Sin embargo, históricamente la secuencia Cretácica ha reportado buenos resultados en términos de producción de hidrocarburos. Este hecho ha renovado el interés en explorar y probar esta secuencia tanto para Hidrocarburos convencionales como para no convencionales. A este respecto, la formación Aguardiente es uno de los principales reservorios de la cuenca. Aunque ha sido perforado y estudiado en diferentes pozos, aspectos claves como su edad, ambiente de depósito y relación cronoestratigráfica con otras unidades aún no es claro. En este trabajo se presentan los resultados del análisis palinológico efectuado en 86 muestras de la Formación Aguardiente y la parte baja de la Formación Capacho. Dichos datos permitieron establecer un marco bioestratigráfico basado en palinomorfos y con el cual fue posible establecer una serie de eventos que sugieren una edad Albiano – Cenomaniano para el intervalo analizado. Adicionalmente se presentan evidencias palinológicas de un posible ambiente de depósito marino somero de estas unidades.

Palabras clave: *Cuenca del Catatumbo Colombia, Cretácico, Palinología, Formación Capacho, Formación Aguardiente.*

RESUMO

A bacia do Catatumbo localiza-se na região nordeste da Colômbia e é a contraparte da bacia de Maracaibo, na Venezuela. Na sequência Cenozoica encontram-se os principais reservatórios. No entanto, historicamente a sequência Cretácica tem revelado bons resultados em termos de produção de hidrocarbonetos. Este fato tem renovado o interesse em explorar e testar esta sequência tanto para hidrocarbonetos convencionais, quanto para não convencionais. Neste contexto, a Formação Aguardiente é um dos principais reservatórios da bacia. Embora tenha sido perfurado e estudado em diversos poços, aspectos chaves como sua idade, ambiente de depósito e relação cronoestratigráfica com outras unidades ainda não está claro. No seguinte trabalho apresentam-se os resultados da análise palinológica praticada em 86 amostras da Formação Aguardiente e a região baixa da Formação Capacho. Esses dados permitiram o estabelecimento de um marco bioestratigráfico baseado em palinomorfos e com o qual foi possível estabelecer uma série de eventos que sugerem uma idade Albiana-Cenomaniana para o intervalo analisado. Além do mais, apresentam-se evidências palinológicas de um possível ambiente de depósito marino superficial destas unidades.

Palavras-chave: *Bacia do Catatumbo Colombia, Cretácico, Palinologia, Formação Capacho, Formação Aguardiente.*

1. INTRODUCTION

Geological Framework

The sedimentary record of the Catatumbo Basin (Figure 1) starts at the end of the Lower Cretaceous (Aptian) with a shallow marine sequence (Tibú, Mercedes, Aguardiente, Cogollo and La Luna Formations). This sequence is followed by fine-grain and sandstone sequences deposited during the Late Cretaceous corresponding to the Colon and Mito Juan Formations (Figure 1). During the Triassic, Jurassic and Cretaceous, Colombia was affected by a rifting related to the separation of North and South America (Jaillard, Soler, Carlier & Mourier, 1990). The sedimentary Cretaceous in the basin was deposited in this environment. The progressive oblique collision between the Caribbean plate and the Northern margin of South America during the end of the Cretaceous and the Early Cenozoic, generated a series of deformation events conditioning the evolution of the Northern Andes and its adjacent basins (Case, Duran, Lopez, & Moore, 1971, Villamil & Pindell, 1998, Montes, Hatcher, Restrepo-Pace, 2005).

Oil production in the Catatumbo basin began in 1920. Although the major reservoirs are found through the Cenozoic, the Cretaceous sequence has also reported good results. Major fields including Carbonera, Petrólea and Río de Oro have reported production from the Cretaceous.

In recent years, the exploratory activity of ECOPETROL in the Catatumbo basin has focused on both conventional and non-conventional (mainly *gas shale*) resources in areas with high structural complexity and deep naturally-fractured reservoirs. Exploratory campaigns often comprise the testing of multiple objectives and reservoirs from different ages. The Aguardiente Formation is one of the most important drilling objectives. Its type section is the Aguardiente Hill (Notestein *et al.*, 1944), in Norte de Santander department in Colombia. This unit was initially described as the upper member of the Uribante Formation (Notestein, Hubman & Bowler, 1944). Sutton (1946) defined it as a Formation (Julivert, 1968). The Aguardiente Formation comprises a sequence of predominantly glauconite sandstone with interbedded carbonaceous shale and

calcareous levels. It has an average thickness of 148 meters. Based on ammonites, Aguardiente has been dated as Albian (Julivert, 1968). This unit overlies the Tibú-Mercedes Formation and underlies the Capacho Formation (Figure 1). The Capacho Formation is the unit that overlies the Aguardiente. Its type section is located in the Capacho Hill, in The Tachira State, Venezuela. Gonzalez (1951, in Julivert, 1968) measured a reference section in the Sardinata – Gramalote Road, in the Riecito River. According to Sutton (1946, in Julivert, 1968) and Rod & Maynic (1954, in Julivert, 1968)) the Capacho Formation corresponds to the stratigraphic interval located between the Aguardiente and the La Luna Formations. This interval was also called the Cogollo Group by Notestein *et al.* (1944) in the Barco Concession, based in the recognition of three Formations: the Lower, Middle and Upper Cogollo. This proposal created confusion in the use of the two terms. For that reason, Maync (in Julivert, 1968 and Richards, 1967 in Julivert 1968) proposed to use only the term Capacho Formation, even in the Barco Concession. According to Gonzalez (1951, in Julivert, 1968) in the Riecito river section, the three members of the Capacho (Lower, Middle and Upper Cogollo of Notestein *et al.*, 1944) are recognized. The Lower Member, studied in this paper, corresponds to a 138 m. series of dark gray to black, hard, partly calcareous and micaceous shales with interbedded limestone in the upper 60 m. These limes are dark gray, argillaceous, wavy and flaggy-to slabby-bedded (Richards, 1957 in Julivert, 1968).

Here we present the palynological results from five wells that drilled the Aguardiente Formation and the Lower Capacho (Table 1). A biostratigraphic framework for this unit was established. Biostratigraphic events including First Appearance Datum (FAD), Last Appearance Datum (LAD) and ACME's (Abundances) were evaluated by the Graphic Correlation method. The palynological data allowed us to make inferences about the possible deposition environment of the unit, as well as its age.

2. EXPERIMENTAL DEVELOPMENT

We analyzed the palynological information from four wells drilled in the Catatumbo basin and one outcrop section (Figure 2, Table 1). A total of eighty-six (86) well- ditch cutting samples were analyzed (Table 1).

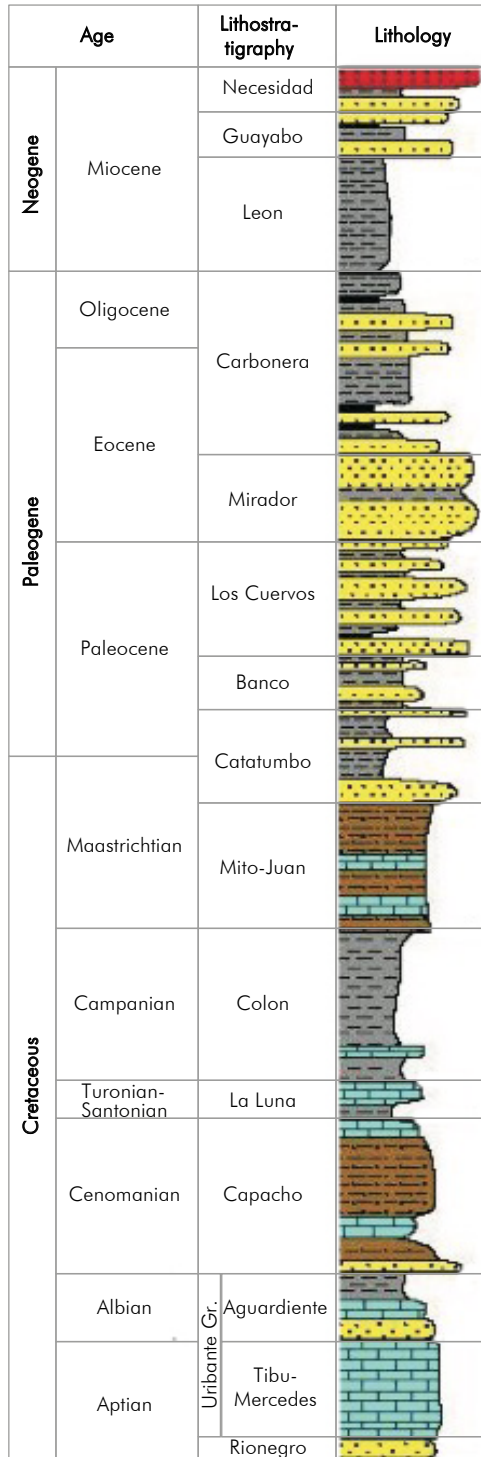


Figure 1. General Cretaceous-Neogene stratigraphic column of the Catatumbo Basin (modified from Notestein *et al.*, 1944, Blanco *et al.*, 2008).

Table 1. Analyzed wells and outcrop section and numbers of samples per section.

Well	Latitude	Longitude	# Analyzed samples
Alamos-1	8.9482	-73.0189	47
Tibu-408	8.699306	-72.739053	16
Carbonera-5k	8.391	-72.515	53
Oripaya-1 ST1	8.0772	-72.4293	31
Sardinata section	8.043	-72.8037	28

Samples were prepared in the Instituto Colombiano del Petróleo (ICP as per its acronym in Spanish) following the standard procedure of digesting the sediments in HCl and HF and then oxidizing (Traverse 2007). The identification of the palynomorphs was performed by comparison with published literature and with the palynological reference collection of fossil palynomorphs hosted at the ICP.

We produced a biostratigraphic framework using Graphic Correlation (Shaw 1964; Edwards 1984), using GraphCor® (Hood 1988). A bivariate (XY) plot (Figure 3) is used to compare the stratigraphic position of biostratigraphic events (First Appearance Datum or FAD, Last Appearance Datum of LAD and high frequencies or ACMES); a line of correlation is drawn to establish the temporal equivalence between sections. The line of correlation can be traced either manually or by using statistic methods, like genetic algorithms (Edwards, 1989, Zhang, 2000). This procedure is applied to all sections (in this case 5) to produce a composite section and to establish the stratigraphic range of all species. The new species range is expressed in terms of composite units (cu) corresponding to the measured units of the Reference Section. Because all the samples used in this study are ditch cuttings, FAD's were not used to avoid the effect introduced by caving. The outcrop section (Sardinata) has low sampling due to a great amount of covered interval, and low recovery due to high thermal alteration. The Alamos-1 well was used as the Reference Section because it is the most complete in terms of sampling and palynological recovery. Two rounds of correlation were performed, reaching the stability of every taxon range. Because of the biostratigraphic events not occurring exactly at the same stratigraphic level across the sections thus, their extrapolation from

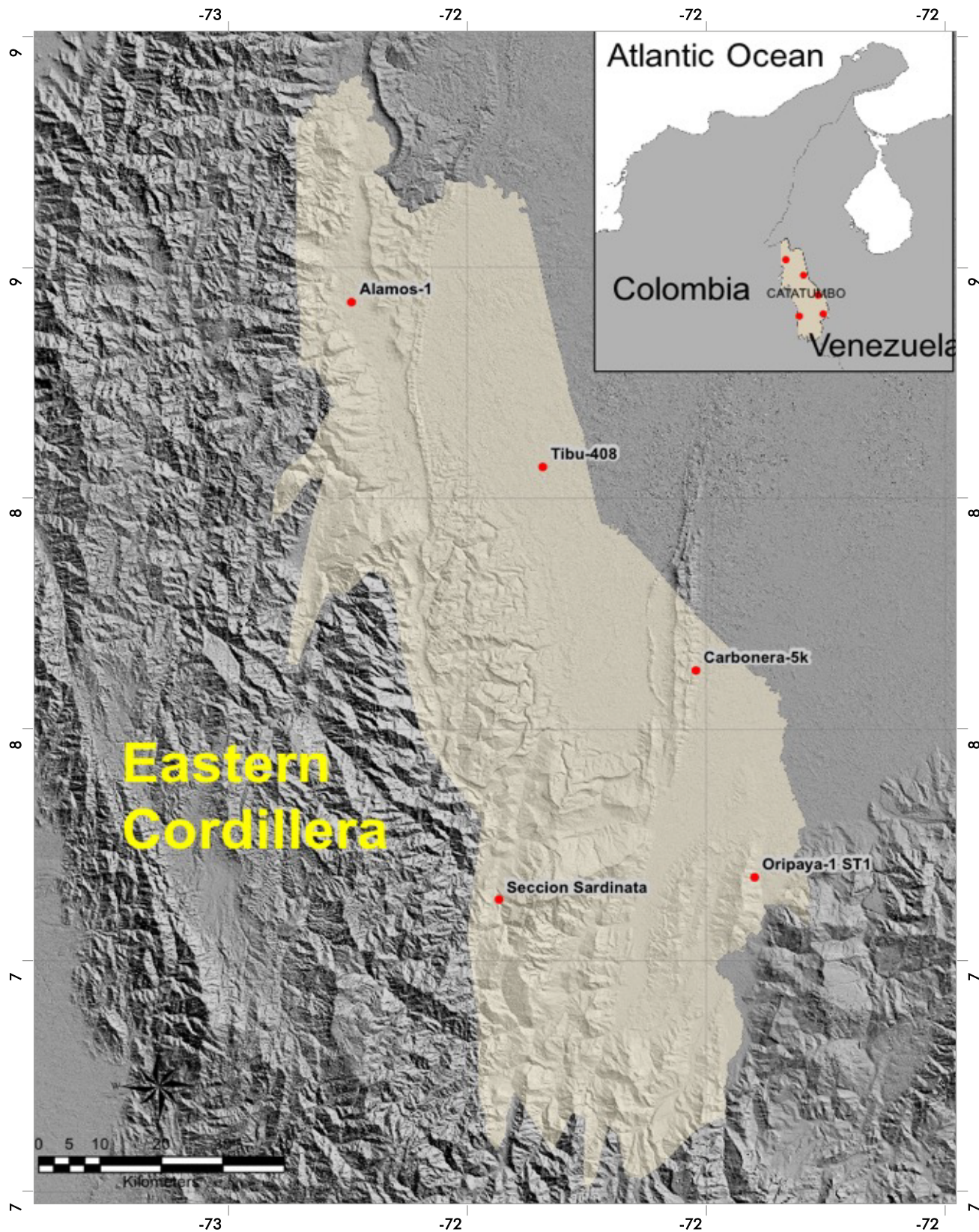


Figure 2. Location of the analyzed sections of this study.

a single section to the composite section); a spreading parameter (Jaramillo *et al.*, 2011, Jaramillo *et al.*, 2005) was calculated in order to evaluate the confidence of the position of each event (in this case LAD and LAD of an ACME) in the Reference Section (Table 2). This is also a way to identify whether each event could be useful as a correlation event. The main idea for this study was to determine how dispersed could the position of each event be in the Reference Section. For this reason, the Spreading parameter was calculated by subtracting the position of the oldest extrapolated LAD and the youngest extrapolated LAD.

The Thermal Alteration Index (TAI, Staplin, 1969, 1977 in Traverse, 2007) was calculated to assess the thermal maturation of the organic matter.

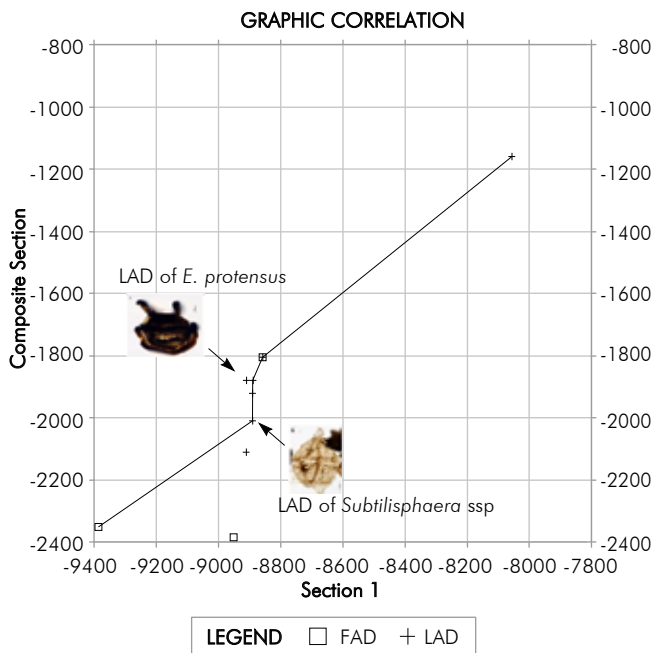


Figure 3. Example of Graphic correlation

3. RESULTS

The recovery of continental organic matter is good, and the palynoflora recovery is moderated. TAI ranges from 2+ in the North to 3 at the South. Common palynomorphs include *Classopollis*, sp., *Classopollis*

classoides, *Afropollis* spp. *Callialasporites dampieri*, *Psilatriteles* sp and *Elaterosporites protensus*. In two wells, (Alamos-1 and Tibu-408, see annex 1) two events with high abundance (ACME) of the dinoflagellate cyst *Subtilisphaera* spp. were observed in the middle part of the Aguardiente Formation.

The preliminary sequence of events is composed by seven (7) palynological events. Five palynological events were identified in the Aguardiente Formation. Most of these events were found only in one or two wells, and very few were found across all the studied sites. From bottom to top, the events are: The LAD of high frequencies of *Subtilisphaera* (*Subtilisphaera* ACME 2), LAD of high frequencies of the *Classopollis* pollen genus (*Classopollis* ACME), the LAD of *Elaterosporites protensus*, again high frequencies of *Subtilisphaera* (*Subtilisphaera* ACME 1), and the LAD of *Callialasporites dampieri* and the genus *Classopollis* and Two events in the Capacho Formation, described by *Psilatriteles* <25mic. ACME (LAD of the ACME) and Dinoflagellates ACME (LAD of the ACME) (Table 2, Figure 4). In all the studied wells a change in the organic matter composition is observed in the Aguardiente – Capacho’s s transition. Aguardiente is dominated by the continental organic matter while, amorphous organic matter dominates the lower part of the Capacho Formation.

Table 2. Sequence of the observed palynological events of the Capacho – Aguardiente Formation and number of wells were the events are observed.

EVENT	TOP (cu)	# wells	Spreading parameter (cu)
Capacho Fm. Top	1 160	5	-----
Psilatriteles <25mic. ACME	1 210	4	341
Dinoflagellates ACME.	1 510	1	Uncertain
Aguardiente Fm. Top	1 804	5	-----
Afropolis jardinous LAD	1 840	2	333
Callialasporites dampieri LAD	1 880	3	20
Classopollis classoides LAD	1 880	4	339
Subtilisphaera spp. ACME 1	1 920	2	80
Elaterosporites protensus LAD	1 950	1	Uncertain
Classopollis spp. ACME	2 010	3	199
Subtilisphaera spp. ACME 2	2 024	2	235

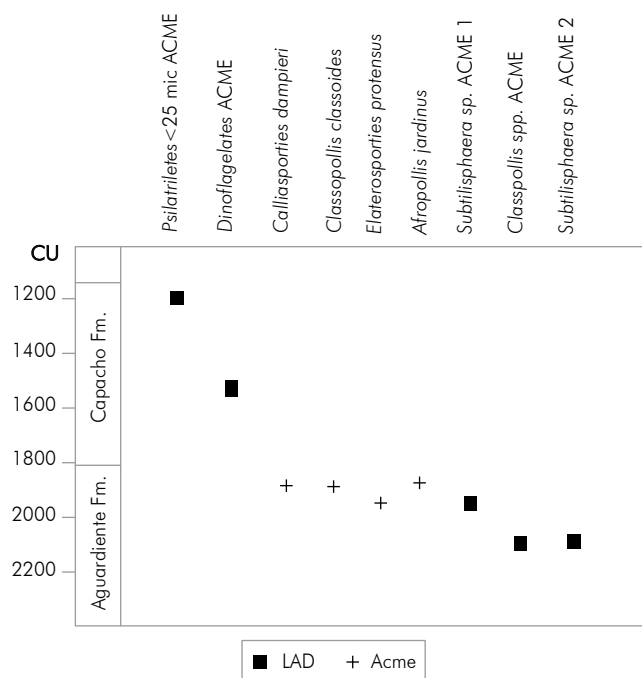


Figure 4. Sequence of identified events and its stratigraphic position in the composite section.

4. RESULTS ANALYSIS

High thermal alteration of the Aguardiente Formation, indicated by our TAI analysis, strongly affects the preservation and recovery of the organic matter and palynomorphs. We found the thermal alteration to be higher in the South (Oripaya -1, TAI 3) than in the North (Alamos -1, TAI 2+). Mondragón *et al.* (2002, internal report) based on vitrinite reflectance (R_o) also concludes that the thermal maturity of the Uribante Group (Tibu, Mercedes and Aguardiente Formations) is very high, ranging from mature to the North to over mature to the South.

Although most of the events keep the same stratigraphic order in all wells, many of them have high spreading parameter (Table 2.) Only *Calliasporites dampieri* records a variation of 20 composite units, but that is not seen in all wells. *Afropollis jardinus*, and *Elaterosporites protensus* LADs, good chronostratigraphic markers are very uncertain. This could be the reflection of the preservation due to Thermal alteration and facies controls. Nevertheless, LADs of *Calliasporites dampieri* and *Afropollis jardinus* and the occurrence of *Elaterosporites protensus* were found in the Aguardiente Formation, and could be

useful for dating purposes. *Calliasporites dampieri* has been reported from the Jurassic in Canada, India and Europe (Norris, 1970, Srivastava, 1966, Srivastava, 1987) up to the Albian in Egypt and Canada (Fensome & Norris, 1982, Ibrahim, 1996). It also has been reported in Tanzania and South America up to the Early Cenomanian (Srivastava, 1987, Brenner, 1976, Herngreen, 1975, Muller, Di Giacomo & Van Erve, 1987, Jaramillo & Rueda, 2004, De la Parra *et al.*, 2011). *Elaterosporites protensus* has been reported from the Late Albian to Early Cenomanian in South America and Africa (Jardine, 1967, Herngreen, 1975, Brenner, 1976, Muller *et al.*, 1987, Batten, 1996, Jaramillo & Rueda, 2004, De la Parra *et al.*, 2011). *Afropollis jardinus* has been recorded in Africa and South America from the Middle Albian (Doyle, Jardine & Doerenkamp, 1982; Ibrahim, Aboul Ela, & Kholeif, *et al.*, 2001) up to the Early Cenomanian (El Beialy, Head & El Atfy., 2010). Herngreen & Dueñas (1995) found these two species associated with *Classopollis* spp., *Cicatricosisporites venustus*, and *Afropollis Jardinus* in the Upper part of the Une Formation of the Llanos Basin and were related to the Albian-Cenomanian South American-African Province (ASA, Herngreen, 1975, 1981, Herngreen and Cholonova, 1981, Herngreen *et al.*, 1996). This association was also found in the Aguardiente. Based on this information, these events could suggest a Middle Albian – Early Cenomanian age for the Aguardiente Formation. The events recognized within the Lower Capachos do not allow to make any age interpretation and are very uncertain. In addition the palynological events could be facies-controlled and/or preservation controlled. However, the Lower part of the Capachos would be Late Albian – Early Cenomanian (Early Cenomanian?) as well, assuming that the association of the ASA Province could be extended to this part of the Formation. These interpretations need to be complemented with more studies of more sections along the basin to calibrate the interpretations and to compare the order of the observed events.

The depositional environment of the Aguardiente Formation has been interpreted as transitional, whereas the Capacho Formation was deposited in a shallow marine environment (Olaya & Linares, 1998). Our palynofacies observations suggest a decrease in the continental supply of organic matter during the accumulation of the lower segment of the Capacho Formation. In addition, within the Aguardiente, many LADs of continental palynomorphs (*Classopollis*, sp., *Cicatricosisporites venustus*, *Classopollis classoides*, *Afropollis* spp.

Callialasporites dampieri and *Elaterosporites protensus*) are observed (Table 2). In Alamos -1 there is a dinocyst ACME in the lower part of the Capacho. This ACME is represented by high frequencies of *Palaeohystricophora infusorioides*, *Subtilisphaera*, *Diphyes* and *Coronifera*. Harris & Tocher (2003) suggest that these assemblages are related to high productivity. These evidences of environmental changes between the Aguardiente and the Lower Capacho could suggest faces control of the palynological events, recognized in this interval.

In Alamos -1 and Tibu - 408 at the Northern part of the basin, two dinocysts ACME events (Subtilisphaera ACME 1 and 2) are recognized. These events suggest some marine influence within the Aguardiente. Toward the South, marine influence is not recognized, probably because the depositional environments were more continental.

5. CONCLUSIONS

- We suggest a probable Albian – Cenomanian age for the Aguardiente – Lower part of the Capacho Formations as a palynological approach.
- Thermal maturity of the Cretaceous Sequence in the Catatumbo Basin is high, being higher toward the South.
- Palynoflora suggests transitional depositional environments for the Aguardiente Formation, while reflecting a deepening in the Lower part of the Capacho Formation.
- Palynological events could be facies controlled, regarding that many LADS were found within Aguardiente and very few within Capacho.
- It is highly recommended to conduct more palynological studies in the Basin, as well as Chronology studies in order to refine age interpretations.

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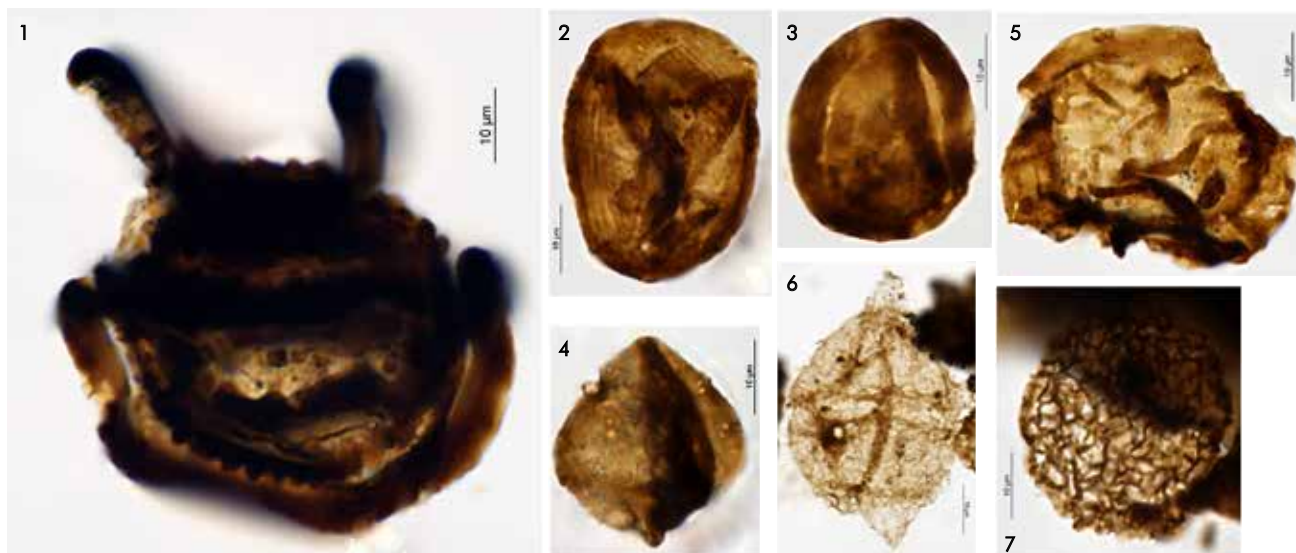
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ANNEX 1

Figure A. Plate 1



1. *Elaterosporites protensus* (Stover 1963) Jardine 1967
2. *Classopollis classoides* Pocock and Jansonius 1961
3. *Classopollis* sp.
4. *Psilatriteles* <25µm
5. *Callialasporites dampieri* (Balme 1957) Dev 1961.
6. *Subtilisphaera* spp. Letin and Williams 1976.
7. *Afropollis jordinus* Doyle, Jardine and Doerekamp 1982

- (Alamos-1 1959' EF:W54-4);
 (Alamos-1 1920' EF:O19-3);
 (Alamos-1 2350' EF:D8);
 (Alamos-1 1300' EF:acme);
 (Alamos-1 2350' EF:R55);
 (Alamos-1 1630' EF:W12-4 acme);
 (Alamos-1 2010' EF:N11(1));