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GEOCHEMICAL ANALYSIS OF THE EAGLE FORD FORMATION ON THE BURRO-PICACHOS PLATFORM, NE OF MEXICO, TO LOCATE AREAS WITH GREATER POTENTIAL TO BE EXPLOITED SUCH AS UNCONVENTIONAL DEPOSITS

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ABSTRACT

In the state of Coahuila in Mexico, the search for unconventional deposits has been developed mainly along the border with the United States of America, due to the Eagle Ford formation, which extends from Mexico to the state of Texas (USA), this formation has produced gas and oil in deposits classified as unconventional.

The Eagle Ford Formation of the Cenomanian -Turonian, deposited in platform and basin environments, consists of clay limestones and calcareous shales, these lithologies have petrophysical and geochemical characteristics depending on the values of organic matter content reported as Total Organic Carbon (TOC), degree of Thermal maturity (Tmax) and the transformation index (Tr). This can be considered as gas and / or oil producing rocks. In this work, the areas with the lowest exploratory risk were studied and analyzed they studied in the Burro - Picachos Platform.

KEYWORDS: *NE of Mexico; Coahuila; Burro - Picachos; Gas shale; Geochemical analysis; Non-conventional.*

I INTRODUCTION

Mexico is among the first ten countries with technically recoverable reserves in shale gas and shale oil deposits, occupying the sixth site with 545 tcf of gas and the eighth site with 13 mmmb of oil (DOE / EIA-0383, 2016) [2].

The National Hydrocarbons Commission (CNH) reports 6 zones with potential for shale gas and shale oil in Mexico (**Figure** 1): 1.- Chihuahua. 2.- Sabinas. 3.- Burro - Picachos. 4.- Burgos. 5.- Tampico - Misantla and 6.- Veracruz (CNH 2016) [1].

In Burro - Picachos, in the state of Coahuila, the exploration of wells associated with unconventional deposits has focused mainly on the continuation of the Eagle Ford formation in Mexico.

Gas shale

The term shale, is used for a wide spectrum of lithologies, ranging from shales, mudstone limestones, siltstones up to fine-grained sandstones.

The content of TOC (Total Organic Carbon) is fundamental to determine the feasibility of a shale gas project, so as the degree of thermal maturity reached (430 ° C <Tmax> 470 ° C) and the transformation index (80% < Tr> 95%) of the organic matter under consideration (Jarvie, Hill, Ruble, & Pollastro, 2007) [4].

Figure 1. Provinces of Shale in Mexico (modified from CNH 2016).

Eagle Ford Formation

The Eagle Ford Formation extends from the United States of America to the NE portion of the Mexican Republic (Meneses SJ, 2015). Donovan (2012) considered that the Eagle Ford Formation was deposited in a transgressive system, overcoming the Buda Formation and underlying the Austin Formation in a concordant manner (Meneses SJ, 2015) [5].

Eagle Ford Formation in Mexico

In the areas of the Tamaulipas Platform and the Sabinas Basin, this formation has been divided informally into two units called as Lower Unit and Upper Unit (Téllez et al, 2011) [6].

Lower unit

Assigned to the basal portion of the stratigraphic sequence of the Upper Cenomanian - Turonian, in the northern region is characterized by a predominant succession of calcareous-carbonaceous shales, with laminar stratification and abundant planktonic micro fauna.

Upper unit

Corresponds to the upper portion of the stratigraphic succession of the Upper Cenomanian - Turonian, is composed generally by an alternation of limestones from dark gray to black, with abundant presence of planktonic fauna.

II.- STUDY AREA

The study area of the Eagle Ford Formation in the NE of the Mexican Republic, was based on the information gathered and the accessibility of the land.

The information was analyzed with the geochemical information of 8 exploratory wells drilled by PEMEX Production Exploration (PEP), located in the state of Coahuila, as well as with technical reports, made by different institutions such as: National Hydrocarbons Commission (CNH), Mexican Petroleum Institute (IMP), and the Federal Electricity Commission (CFE).

Three field trips were carried out, with the support of engineers from the Super intendency of

North Zone Studies of the Federal Electricity Commission (CFE), in areas that did not represent a high safety risk.

The analysis area covers approximately 12,137 km2 of the Burro - Picachos Platform in the State of Coahuila (**Figure** 2).

Eagle Ford Formation as source rock for HC's

Depending on the content of total organic carbon (TOC), maximum temperature (Tmax), hydrogen index (HI), oxygen index (OI), type of hc's (S2 / S3) and potential producer (PP) (**Table** 1), the first assessment of the area was carried out, to determine, the possibility of the existence of a source rock of oil and gas in the study area.

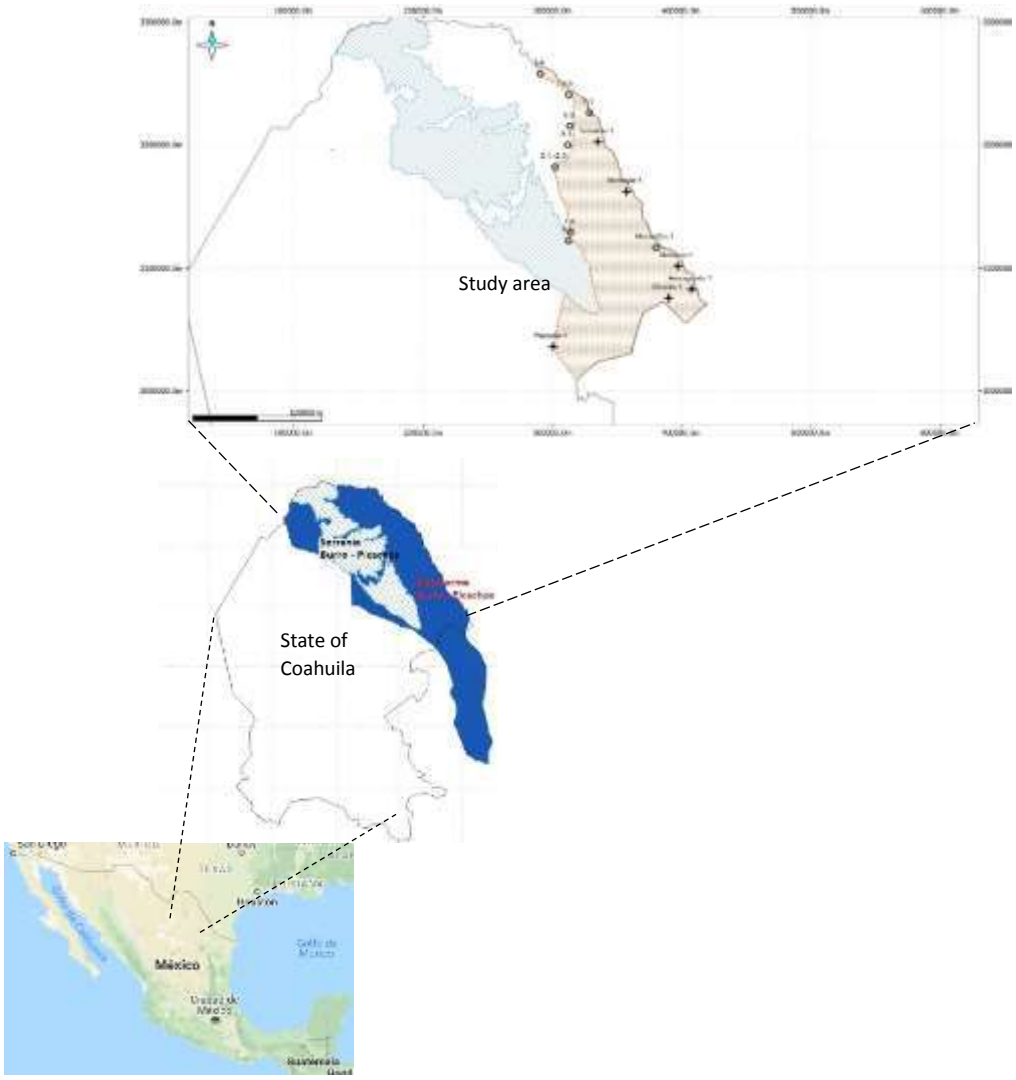

Figure 2. Study area.

	h	TOC	S1	S2	S3	Tmax	HI	OI	PP
Chucla-1	147	1.17	0.07	1.05	0.75	458	128.81	96.13	1.13
Emergente-1	135	1.16	0.05	1.64	0.51	443	175.50	55.00	1.69
Gamma-1	227	1.68	0.26	2.34	0.42	446	203.28	44.12	2.60
Habano-1	120	2.28	0.04	1.35	0.62	480	72.38	33.15	1.39
Nomada-1	215	1.45	0.16	2.03	0.38	427	169.22	33.13	2.20
Trilobite-1	83	3.47	1.66	10.21	0.58	433	350.38	23.44	10.61
Montañes-1	242	1.03	0.05	1.79	0.45	448	254.38	82.12	1.84
Percutor-1	66	2.85	0.04	0.34	0.34	580	12.08	13.46	0.38
Outcrop		0.71	0.20	1.69	0.72	455	146.21	184.79	1.90

Table 1. Geochemical characteristics in the study area.

Considering the cut-off values of TOC, Tmax, S2 / S3 and PP for a source rock, whose values are shown in **Table 2.**

TOC (%)	Capacity
<0.5	Poor
0.5-1.0	Regular
1.0-2.0	Good
>2.0	Very good to excellent

Tmax	Product
<430	Immature
430-460	Oil
>460	Gas

PP	Potential
<.5	Very weak
.51 - 2.00	Weak
2.01 - 5.00	Medium
5.01 - 20.00	Good
> 20.00	Very good

S2/S3	
< 2	Gas
> 5	Oil

Table 2. Cut-off values for TOC, Tmax, PP and S2 / S3 of a hc's source rock.

According to the amount of TOC, the samples can be cataloged as source rocks from regular to excellent, the Tmax data, indicate that the Eagle Ford Formation entered the maturity window, except for the Percutor -1 and Habano-1 wells (over maturity), the type of hydrocarbon generated (S2 / S3), indicates the presence of oil and gas in all the wells, however, the Percutor -1 well only presents gas, on the other hand the potential producer of the wells (PP), is between weak and medium.

While the hydrogen index (HI) and oxygen index (OI) indicate that the predominant kerogen is mainly type III, gas generators (**Figure** 3).

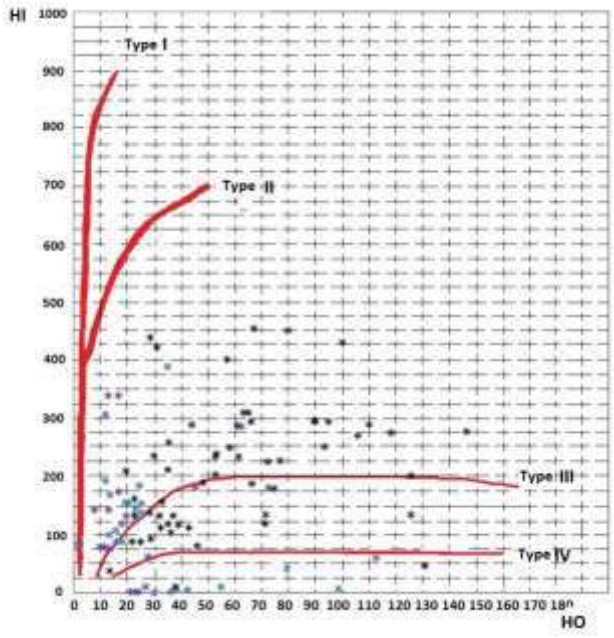

Figure 3. Type of kerogen predominant in the study area.

III.- DELIMITATION OF UNITS IN THE EAGLE FORD FORMATION IN THE STUDY AREA

Because the Eagle Ford Formation presents variation in the content of TOC, the analysis of the paleontological and lithological content in each well was carried out, to establish the existence of units that limit zones with similar characteristics.

The paleontological information of the wells indicates the presence of four fossils characteristic of the Upper Cenomanian to the Upper Turonian in the study area (**Table 3**)

Age	Biozone	Facie
Upper Turonian	Marginotruncana	Middle -external shelf and slope
Middle Turonian	Helvetoglobotruncana helvetica	External shelf, upper slope, euxinic basin
Early Turonian - Late Turonian	Whiteinella archaeocretacea	Inferior slope to basin in occasions euxinic
Upper Cenomanian	Rotalipora	Euxinic basin

Table 3. Characteristic fossils in Eagle Ford formation in the study area.

The top, bases and thickness of the units, can be identified by the behavior of high values in the curves of the gamma-ray registers, presenting some intervals with lower readings that are associated with the presence of limestone and other high readings in response to the presence of shales.

With the geochemical, paleontological data and geophysical record information (Gamma Rays), the Eagle Ford Formation can be subdivided into three units (**Table** 4):

Unity A.- Biozone *Marginotrucana,* predominantly limestone, deposited on platform.

Unity B.- Biozone *Helvetoglobotruncana* Helvetica and *Whiteinella archaeocretacea*, with intercalation of calcareous and calcareous shales, located on external platform and slope.

Unity C.- Biozone *Rotalipora*, whose main lithology are black shales deposited in suboxic basin.

Well	Depth (m)					Thickness (m)			
	Top	Base	Unity A	Unity B	Unity C	Well	Unity A	Unity B	Unity C
Trilobite -1	364	472	364	380	425	108	16	45	47
Nómada-1	960	1175	960	1004	1115	215	44	111	60
Montañes-1	1325	1602	1325	1501	1550	277	176	49	52
Gamma-1	1603	1830	1603	1732	1779	227	129	47	51
Habano-1	1980	2100	1980	2022	2056	120	42	34	44
Emergente-1	2351	2545	2351	2457	2508	194	106	51	37
Chucla-1	1680	1860	1680	1740	1840	180	60	100	20
Percutor-1	1265	1532	1265	1395	1490	267	130	95	42
Outcrop	0	127	0	33	87	127	33	54	40

Table 4. Delimitation of units A, B and C based on fossil content and Gamma Ray record

The criterion for the division proposed by this author is based mainly on the deposit environment, in such a way that, in an external and medium platform environment, the oxygen content is greater (unit A); a reducing environment, associated with a euxinic basin (unit C), leaving the external platform and slope areas as criteria to delimit unit B.

IV.- DEGREE OF HETEROGENEITY OF THE MAIN GEOCHEMICAL CHARACTERISTICS

The analysis of the degree of heterogeneity was carried out, using the Dykstra Parson method (**expression** 1), with the purpose of determining if it is possible to use the weighted averages of the main geochemical properties, in each proposed unit.

$$V = \frac{k_{50} - k_{84.1}}{k_{50}} \qquad \text{expression 1}$$

Where:

V = Coefficient of variation (heterogeneity).

K50 = Value of the 50th percentile obtained in the double log graph.

K84.1 = Value of the 84.1 percentile obtained in the double log graph.

The Dykstra - Parson method is generally applied to permeability, but can be extended to treat other properties of the rock (Tiab & Donaldson, 2004) [7], in this work it was used to know the degree of heterogeneity of: COT, Tmax, PP and S2 / S3.

The method indicates the degree of heterogeneity (V) according to the following values:

01 to 0.25 low grade.

0.25 to 0.50 medium grade.

0.50 to 1.00 degree high.

The results indicate that the proposed units have a degree of medium heterogeneity, so the calculation of weighted averages can be applied reliably.

Associating the content of TOC, Tmax, S2 / S3 and PP, weighted to the thickness, with the degree of heterogeneity, **Table** 5 is constructed, where the heterogeneity index has been colored: high-red color, medium-yellow color, low-green color.

Unity		Trilobite-1	Nomada-1	Montañes-1	Gamma-1	Habano-1	Emergente-1	Chucla-1	Percutor-1	Outcrop
A	Top	364	960	1325	1603	1980	2351	1680	1265	0
	Base	380	1004	1501	1732	2022	2457	1740	1395	0
	h (m)	16	44	176	129	42	106	60	130	0
	TOC		0.64	0.65	0.86	1.44	0.92	0.55		0.63
	Tmax		441	447	444	446	444	452		433
	S2/S3		4.8	3.19	4.71	2.8	3.27	1.63		3.22
	PP		1.84	1.53	1.99	1.56	1.77	1.13		1.62
B	Top	380	1004	1501	1732	2022	2457	1740	1395	0
	Base	425	1115	1550	1779	2056	2508	1840	1490	0

	h (m)	45	111	49	47	34	51	100	95	0
	TOC	1.94	1.17	1.72	1.88	2.44	1.81	1.78		1.03
	Tmax	432	447	449	447	506	438	467		447
	S2/S3	12.27	7.07	5.36	6.33	0.82	3.2	1.42		7.8
	PP	7.54	2.28	2.33	2.52	0.62	1.5	0.99		3.1
	Top	425	1115	1550	1779	2056	2508	1840	1490	0
	Base	472	1175	1602	1830	2100	2545	1860	1532	0
	h (m)	47	60	52	51	44	37	20	42	0
C	TOC	5.14	2.44		3.87	3.41			3.62	0.27
	Tmax	434	440		451	532			586	438
	S2/S3	26.06	5.74		9.89	2.15			1.18	0.57
	PP	13.98	2.02		4.61	1.47			0.45	0.2

Table 5. Content of TOC, Tmax, S2 / S3 and PP, associated with the degree of heterogeneity.

As shown in **Table 5**, the geochemical values in unit's B and C meet the minimum requirements, to be considered in the evaluation of a source rock of HC's.

Spatial distribution of the main geochemical characteristics.

The spatial distribution of the different geochemical properties can be inferred, by means of different methods of interpolation and extrapolation, for this work the SURFER and MOVE computer programs were used, both programs perform the interpolation and extrapolation, by means of geostatistics (kriging).

Depth, index of heterogeneity (V) and TOC

The depth maps (**Figure** 4), the distribution of TOC (**Figure** 5) and the degree of heterogeneity (**Figure** 6) indicate that, in the study area, the Eagle Ford Formation deepens to the SE, with an average TOC content of 2% and a decrease in the degree of heterogeneity towards the same direction.

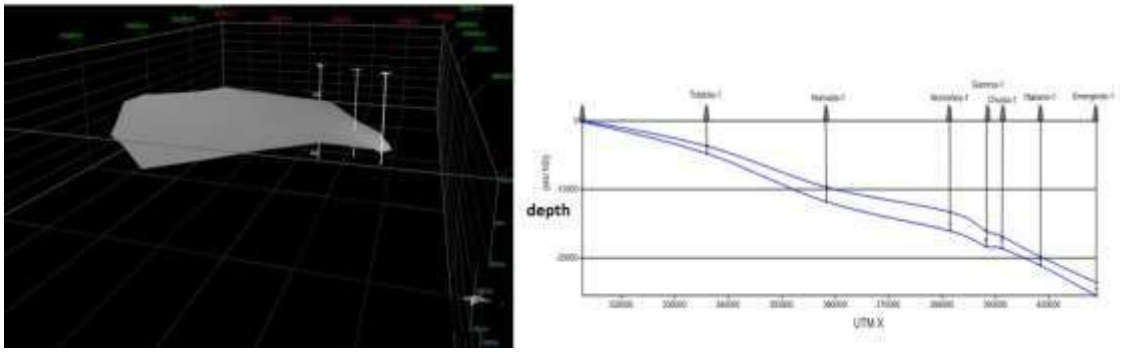

Figure 4. Scheme of the distribution of the tops and thicknesses of the Eagle Ford formation on the platform Burro - Picachos.

The Southeast of the area of analysis, presents favorable values, in terms of the content of TOC (> 1%) and the degree of heterogeneity (0.3 to 0.5), which is why a new area is proposed, which represents a lower exploratory risk.

Considering that, the distribution of weighted TOC to the thickness, in Unit A is low, and its degree of high heterogeneity, only the TOC analysis and the heterogeneity index were performed for the B and C units proposed in this new exploration area (**Figures** 7a, 7b and 7c).

Using the method proposed by Dykstra-Parson, we determined degree that the of heterogeneity in the TOC distribution of each proposed unit, a more uniform behavior in the NE-SW direction, and the heterogeneity index which is smaller in the E-W direction and presents better values of TOC, Tmax, thicknesses, VRo and TR, so it is considered as an appropriate area for the development of a gas shale.

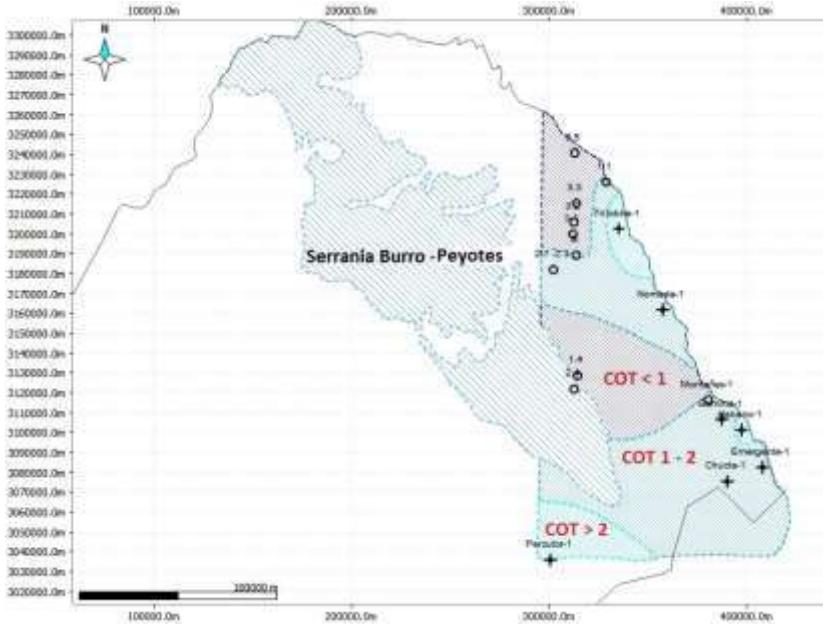

Figure 5. Distribution of TOC weighted to the thickness in the analyzed area.

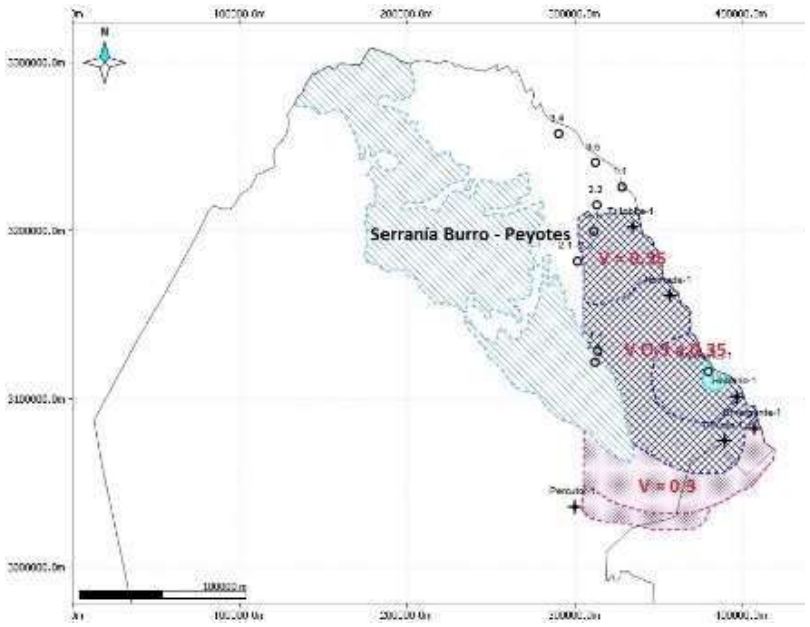

Figure 6. Distribution of heterogeneity values in the analyzed area.

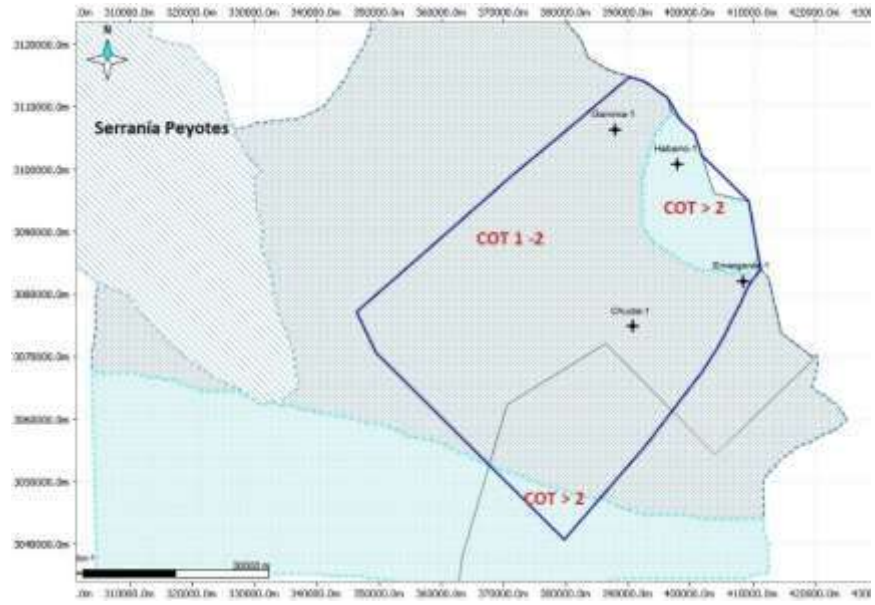

Figure 7a. Map of distribution of the TOC of unit B in the area of interest.

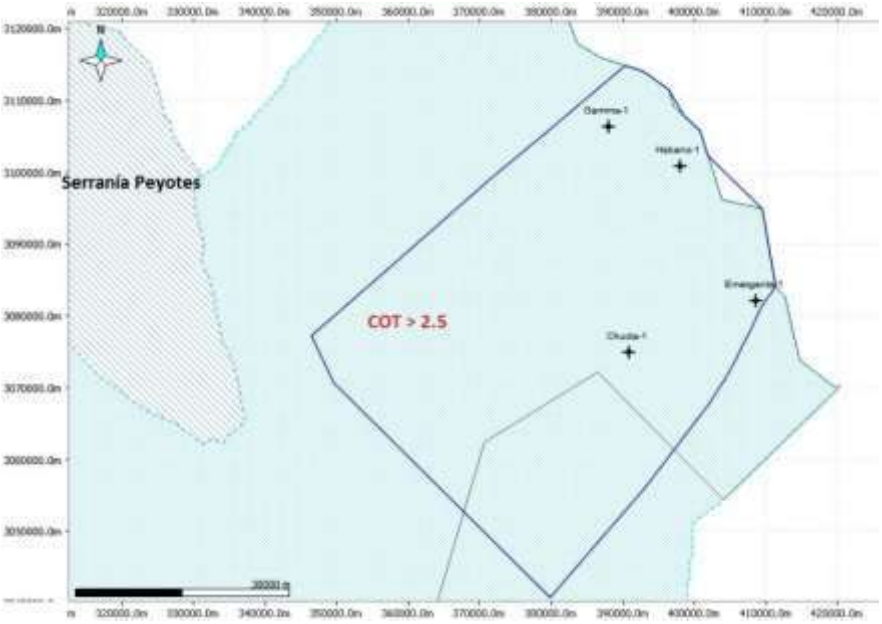

Figure 7b. Distribution map of the COT of unit C in the area of interest

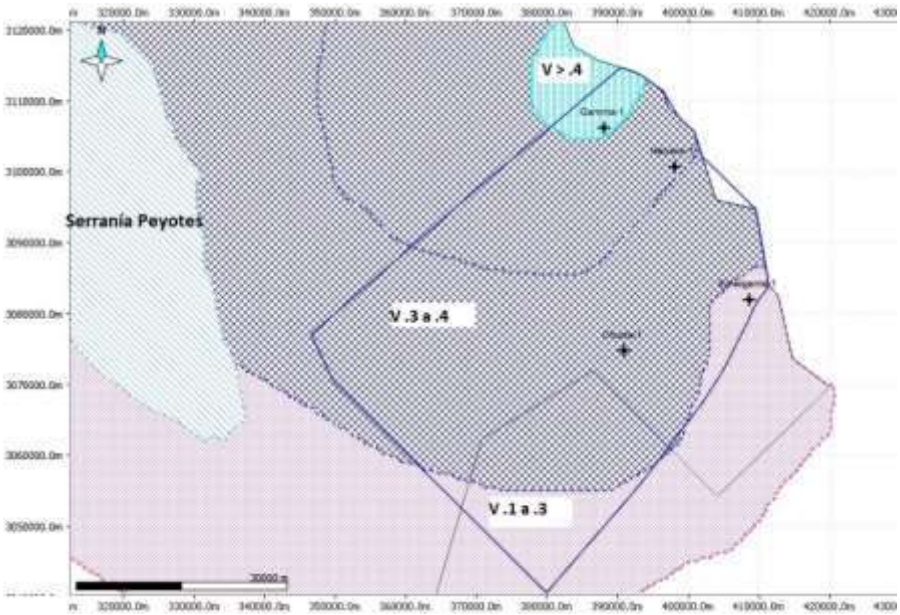

Figure 7c. Map of the degree of heterogeneity of the Eagle Ford formation in the area of interest.

The analysis area of the Eagle Ford formation, covers approximately 12,137 km2 of the Burro - Picachos Platform in the State of Coahuila, as indicated by its geochemical properties of TOC, HI/ HO, Tmax; S2 / S3 and PP, have a total organic carbon content of regular to excellent, coming from type III - II kerogen, enter the hydrocarbon generation window, producing gas and oil, although its production potential is weak to medium, but because of the variability in the content of TOC vertically, it is necessary to establish subdivisions in that formation.

In this area, in the SE - NW direction, the degree of heterogeneity is approximately 0.3 to 0.4, while the content of TOC for unit B is 2% and for unit C greater than 2.5%.

Therefore, the area of lowest exploratory risk for the Burro - Picachos platform is reduced to the polygon shown in **Figure** 8.

Main geochemical characteristics of the area with lower exploratory risk.

To evaluate a potential area of gas and oil we can use geochemical parameters, based on thermal maturity, these data include the total organic carbon content, TOC, degree of thermal maturity (Tmax), and derived from the Rock eval analysis, values of reflectance of vitrinite (Ro), hydrogen index (HI), as well as the transformation index (Tr) reached (Jarvie, Hill, & Pollastro, 2005) [3].

Based on the formulas proposed by Jarvie (2001):

The value of the reflectance (VRo) of the vitrinite is:

Cal. % VRo (of Tmax) = 0.0180 x Tmax – 7.16 [%]

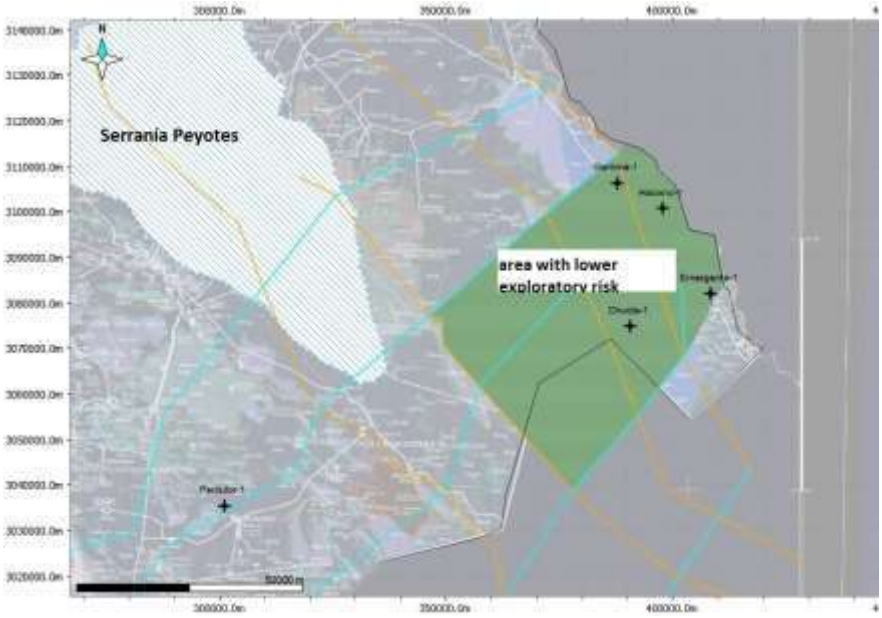

Figure 8. Map showing the area with the lowest exploratory risk.

The original generation potential can be calculated using the average value of carbon contained in hydrocarbons (83%) and increasing the generator potential S2.

Transformed TOC = original TOC - present TOC [wt. %]

S2 original = COT transformed / 0.083 + S2 present [mg hc's / g rock]

While the original value of the hydrogen index (HI) is calculated with the formula:

Original HI = original S2 / original COT x 100 [mg HC / g COT]

From the results generated, the transformation ratio of the kerogen (Tr) can be calculated.

Tr (Transformation index) = (original IH - present IH) / original IH [%]

The calculated values, using the method proposed by Jarvie (2001), for the wells analyzed, are shown in **Table** 6.

	Well Chucla-1	Well Emergente-1	Well Gamma-1	Well Habano-1	Well Nómada-1	Well Trilobite-1	Well Montañes-1	Well Percutor-1	Outcrop
Ro	124	80	83	177	49	63	89	311	4
Tmax	508	442	427	503	416	433	427	576	455
Tr	89	69	63	90	69	43	58	99	74
HI	119	173	196	59	161	338	254	12	146

Table 6. Values of Ro, Tmax, Tr and IH, of the wells analyzed.

The suggested cut-off values for a shale gas play proposed by Jarvie 2005 are (**Table** 7):

TOC	Tmax	Tr	VRo
2.0 %	455°C	80%	1.0 %

Table 7. Cut-off values of Ro, Tmax, Tr and IH, for a shale gas play (Jarvie 2005).

Once the area with the lowest exploratory risk is determined, the geochemical properties mentioned in previous paragraphs are analyzed, with the purpose of determining if, the Eagle Ford formation, meets the necessary geochemical conditions to be considered as an unconventional oilfield.

In the area with the lowest exploratory risk, the Chucla-1 and Habano-1 wells meet the minimum characteristics of a shale gas, as shown in **Figure 9**.

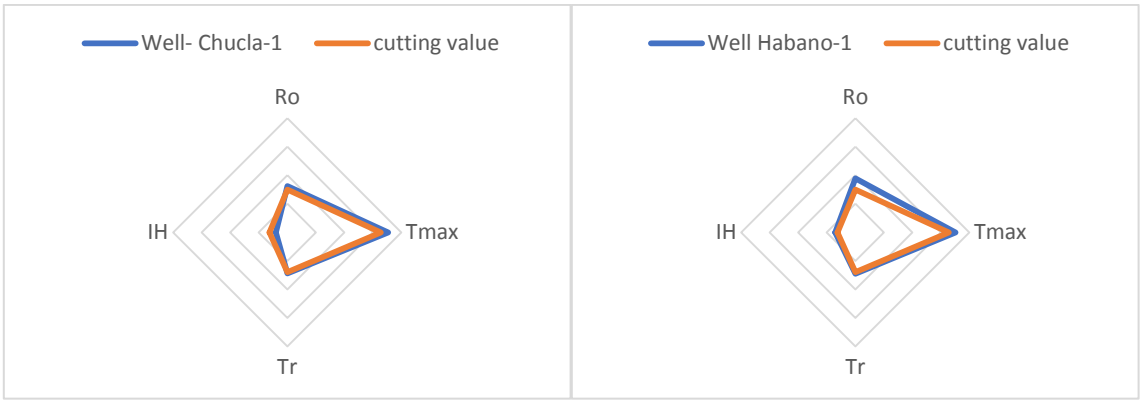

Figure 9. Graphs for the Chucla-1 and Habano-1 wells, in which it is observed that both wells meet the minimum characteristics for the development of a shale gas.

Therefore, the area of greatest development viability is limited to 928.65 km² (**Figure** 10).
Additionally, the proposed B and C units of the Chucla-1 and Habano-1 wells can be considered as a viable prospect in a shale gas project on the Burro-Picachos platform (**Figure** 11).

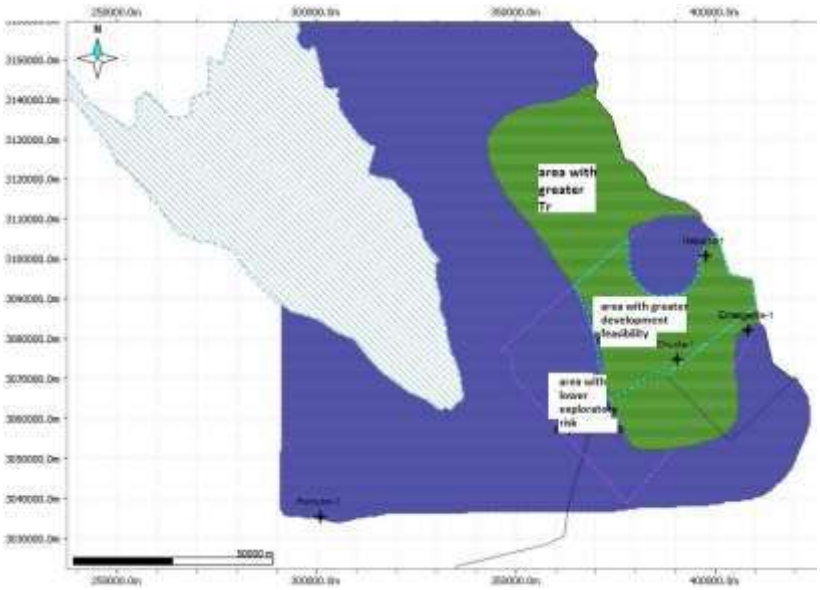

Figure 10. Map showing the area with the lowest exploratory risk for a shale gas.

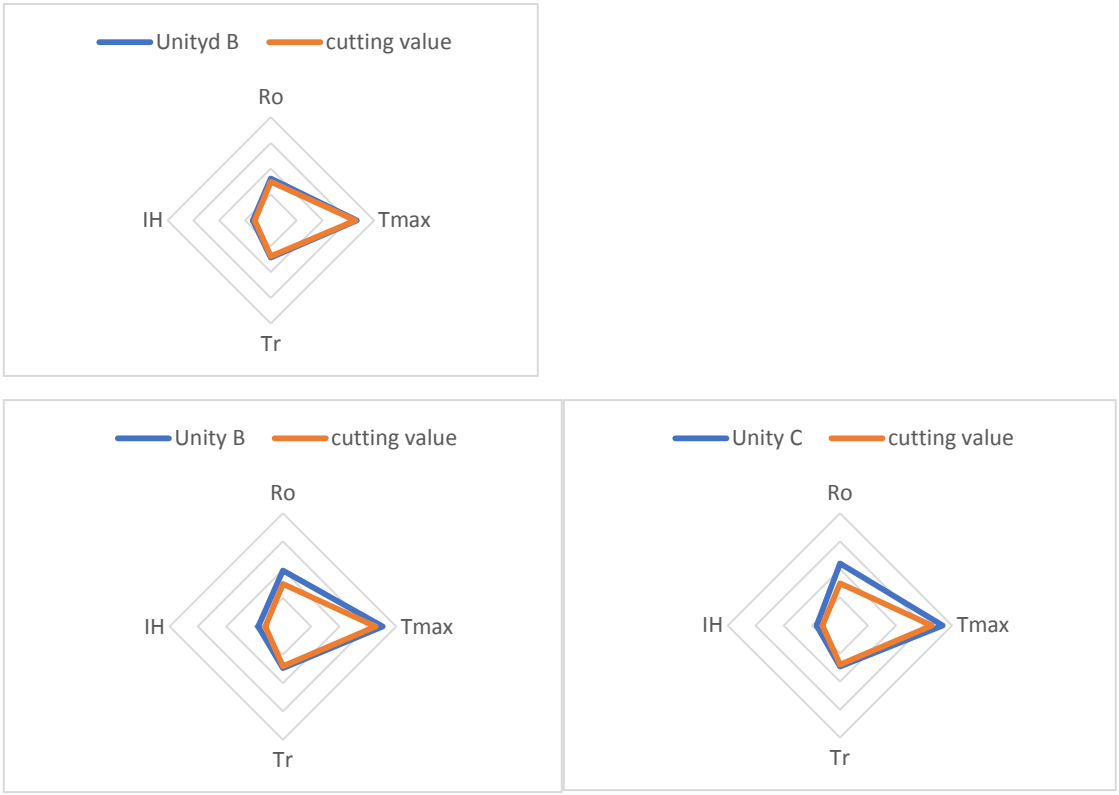

Figure 11. Graphs for the Chucla-1 and Habano-1 wells, in which it is observed that both wells meet the minimum characteristics for the development of a shale gas.

V.- CONCLUSIONS

The analysis area of the formation Eagle Ford, covers approximately 12,137 km2 of the Burro - Picachos Platform in the State of Coahuila.

The Eagle Ford Formation, as indicated by its geochemical properties of TOC, IH / OH, Tmax; S2 / S3 and PP have a total organic carbon content going from regular to excellent, coming from type III and II kerogen, enter the window of generation of hydrocarbons, producing gas and oil, although their production potential is weak to medium and it can be considered it as a hydrocarbon generating formation.

Geochemical analyzes indicate that some areas are susceptible to being developed as unconventional deposits, however, because of the variability in the content of TOC vertically, it is necessary to establish subdivisions in the formation.

a) Biozone *Marginotrucana,* predominantly limestone, deposited on platform, TOC 0.88; Tmax 432; Tr 65.21.
b) Biozone *Helvetoglobotruncana* Helvetica and *Whiteinella archaeocretacea*, with intercalation of calcareous and calcareous shales, located on external platform and slope, TOC 1.78; Tmax 443; Tr 74.87. COT 3.11; Tmax 483; Tr 79.25.
c) Biozone *Rotalipora*, whose main lithology are black shales deposited in suboxic basin, TOC 3.11; Tmax 483; Tr 79.25.

When applying the degree of heterogeneity method proposed by Dykstra-Parson, the horizontal similarity of the content of TOC, Tmax and Tr, in each proposed unit is determined, so that a quantitative criterion of the MO distribution can be considered, Tmax and Tr in the study area.

By associating the geochemical parameters, cited in the previous paragraph, with the degree of heterogeneity for each proposed unit, it was possible to establish an area that meets the geochemical parameters of an unconventional gas field (shale gas) to the SE of the Burro - Picachos platform), where:

- The spatial distribution, top depth, TOC, Tmax, transformation index (Tr), vitrinite reflectance value (VRo), and heterogeneity index (V), show less variation in the NE - SW direction, the study area.

- The proposed unit's B and C have a lower exploratory risk in the NE-SW direction on the Burro-Picachos platform.

- The Southeast zone (approximately 928.65 km²), of the area, of study, presents better values of TOC, Tmax, thicknesses, VRo and TR, reason why it is considered as an appropriate area for the development of a gas shale.

Nomenclature

HI	Hydrogen Index [mgHC/gTOC]
OI	Oxygen Index [mgCO2/gTOC]
PP	Potential Producer
VRo	Reflectance of vitrinite [%]
S1	Free Oil [mg HC/g rock]
S2	Kerogen Yield [mg HC/g rock]
Tmax	Thermal maturity [°C]
TOC	Total Organic Carbon [weight %]
Tr	Transformation Index [%]
V	Coefficient of variation

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