Organic Geochemistry Atlas of Colombia
2021 Update

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Dirección de Hidrocarburos SGC

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Outline

- Introduction
- Methodology (what we did)
- Content examples
- Concluding remarks
- Acknowledgments

Introduction

- Project of the Direction of Hydrocarbons of the Colombian Geological Survey, supported and financed by the ANH.
- Main objective, to update the existing organic geochemistry database of the ANH, and the Organic Geochemistry Atlas of Colombia – 2010.
- Started in May 2021 and ended in December 2021.

Introduction

What is the Organic Geochemistry Atlas of Colombia?

A graphical summary of the organic geochemistry data available in the Colombian basins, showing the characteristics of the source rocks, crude oils and gases, that can be used as a guide for explorationists on the prospectivity of the basins.

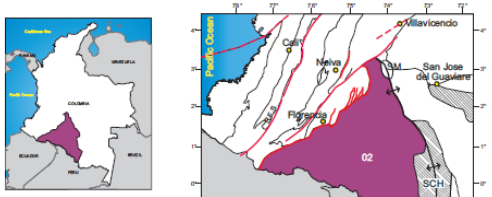
This document was first published in 2006 and later updated in 2009 and 2010.

Introduction

What is the Organic Geochemistry Atlas of Colombia? Version 2010

Generalities

CAGUAN - PUTUMAYO BASIN
LOCATION AND BOUNDARIES



BOUNDARIES

Northwest: Eastern Cordillera Foothills fault system
Northeast: Sierra de la Macarena (SM)
East: Structural high, including the Serrania de Chiribiquete (SCH)
South: Ecuadorian-Peruvian International border

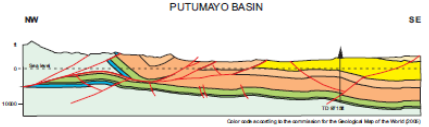
Paleozoic sedimentary rocks forming structural highs
Basement high

From Barrero et al., 2007

The source rock geochemical information interpreted for the Caguán-Putumayo Basin includes %TOC and Rock-Eval Pyrolysis data from 2912 samples taken in 64 wells; additionally 335 organic petrography samples from 56 wells were interpreted.

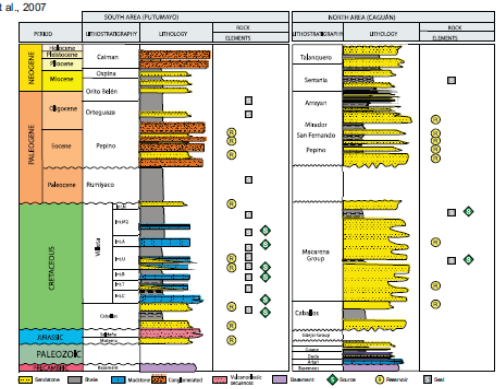
Crude oil and extracts information from 124 bulk analysis samples, 403 liquid chromatography samples, 330 gas chromatography samples,582 biomarker samples and 90 isotopes samples were also interpreted.

SCHEMATIC CROSS SECTION
PUTUMAYO BASIN



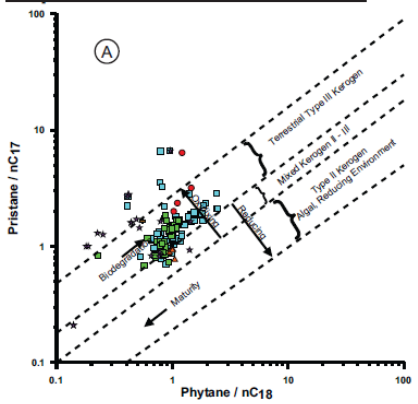
Paleozoic Jurassic Lower Cretaceous Upper Cretaceous
Paleogene Neogene

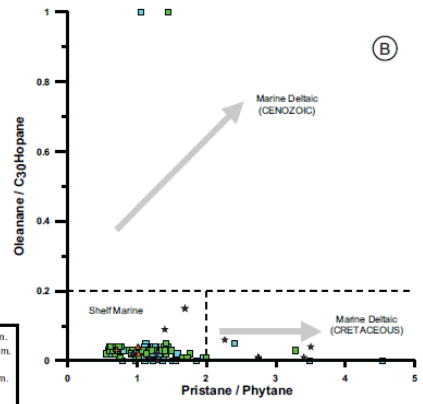
From Barrero et al., 2007



From Mojica et al., 2010

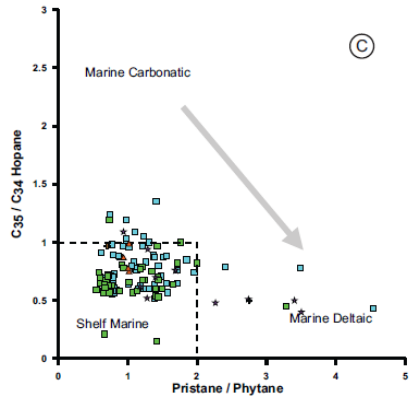
Depositional Environments





LEGEND

- CABALLOS Fm.
- MACARENA Fm.
- PEPINO Fm.
- RUMIYACO Fm.
- UNKNOWN
- VILLETA Fm.



- The Phytane/nC18 vs Pristane/nC17 graph indicates that most of the oils have origin from terrestrial organic matter (Type III kerogen) deposited in an oxidizing environment and have suffered low biodegradation. There are also some samples in the mixed kerogen range suggesting a source with terrestrial and marine organic matter (Type II and III kerogens) deposited in more reducing conditions (Figure A).

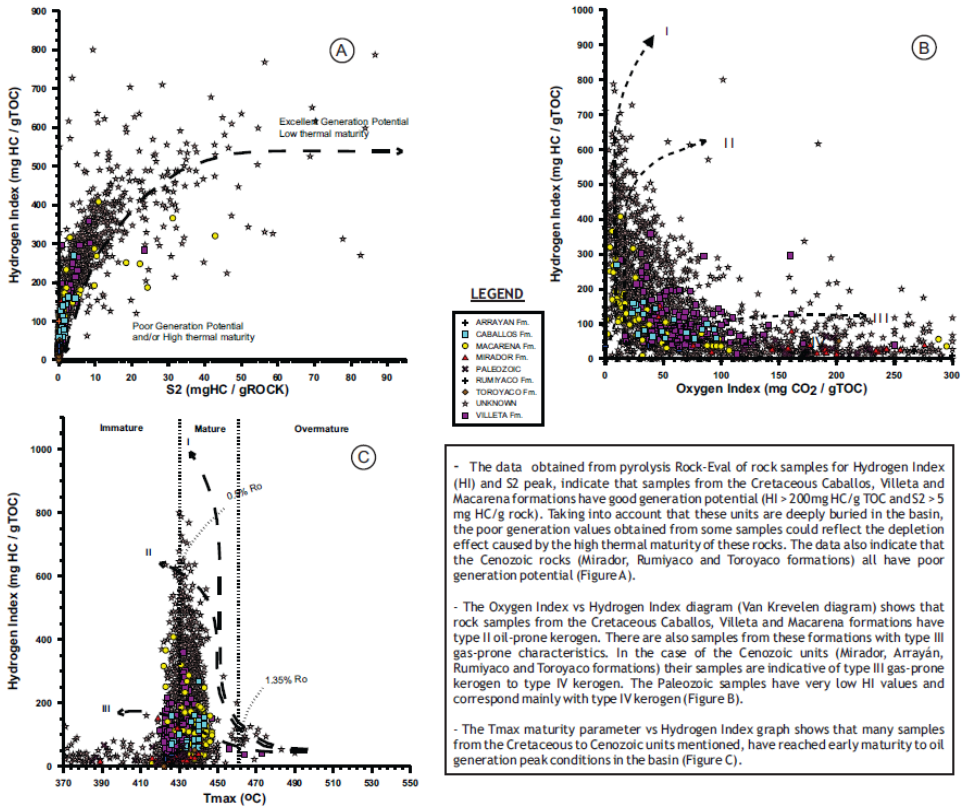
- The Pristane/Phytane vs Oleanane/C30 Hopane (Oleanane Index) graph shows that most of the oils have low oleanane index values (<0.2) and Pr/Ph values (<2) which indicates that these oils are generated from source rocks deposited in shelf marine environments. There are some samples with low oleanane index values but high Pr/Ph (>2) indicating that these oils were generated from source rocks deposited in marine deltaic environments. The oleanane index has been also used as an age indicator of the source rock, with high oleanane values for oils generated in Cenozoic rocks and low oleanane values in oils from older rocks (Figure B).

- The Pristane/Phytane vs C35/C34 Hopane (Homohopane index) graph shows that most oil samples have Pr/Ph values below 2 and C35/C34 Hopane below 1, indicating that these oils were generated from siliciclastic rocks deposited in a shelf marine environment. Additionally there are some samples with low homohopane index but higher Pr/Ph values (>2) indicative of siliciclastic rocks deposited in marine deltaic environments (Figure C).

Introduction

What is the Organic Geochemistry Atlas of Colombia? Version 2010

Source Rock Characterization

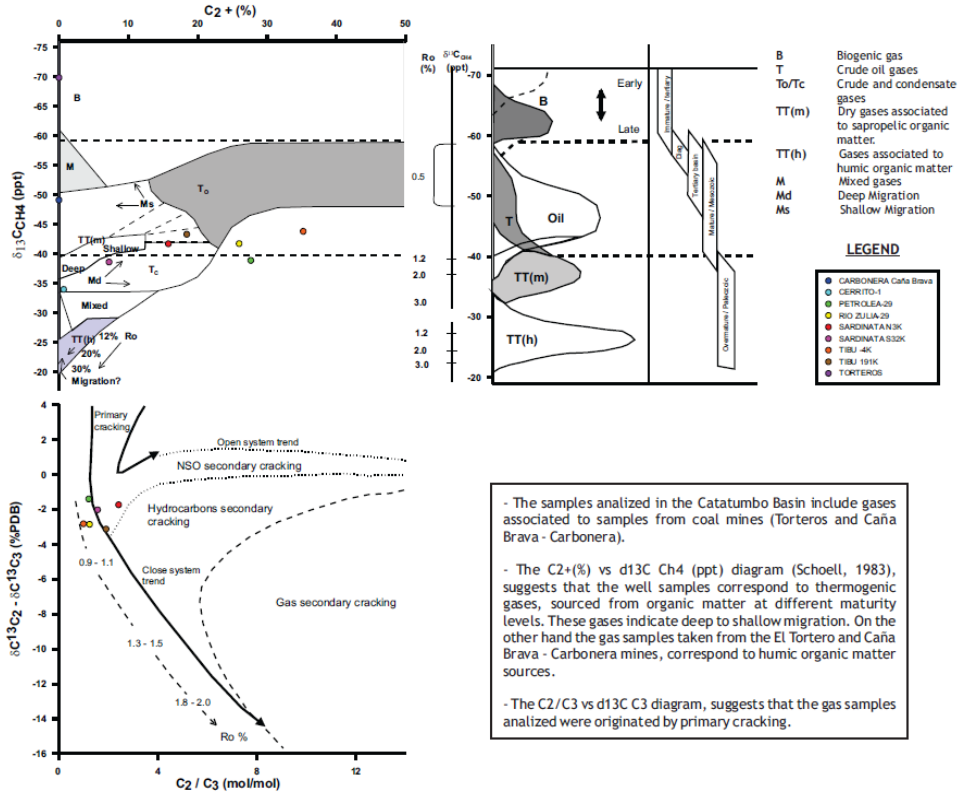


- The data obtained from pyrolysis Rock-Eval of rock samples for Hydrogen Index (HI) and S2 peak, indicate that samples from the Cretaceous Caballos, Villeta and Macarena formations have good generation potential (HI > 200mg HC/g TOC and S2 > 5 mg HC/g rock). Taking into account that these units are deeply buried in the basin, the poor generation values obtained from some samples could reflect the depletion effect caused by the high thermal maturity of these rocks. The data also indicate that the Cenozoic rocks (Mirador, Rumiyaco and Toroyaco formations) all have poor generation potential (Figure A).

- The Oxygen Index vs Hydrogen Index diagram (Van Krevelen diagram) shows that rock samples from the Cretaceous Caballos, Villeta and Macarena formations have type II oil-prone kerogen. There are also samples from these formations with type III gas-prone characteristics. In the case of the Cenozoic units (Mirador, Arrayán, Rumiyaco and Toroyaco formations) their samples are indicative of type III gas-prone kerogen to type IV kerogen. The Paleozoic samples have very low HI values and correspond mainly with type IV kerogen (Figure B).

- The Tmax maturity parameter vs Hydrogen Index graph shows that many samples from the Cretaceous to Cenozoic units mentioned, have reached early maturity to oil generation peak conditions in the basin (Figure C).

Gas Characterization



- The samples analized in the Catatumbo Basin include gases associated to samples from coal mines (Torteros and Caña Brava - Carbonera).

- The C2+(%) vs d13C Ch4 (ppt) diagram (Schoell, 1983), suggests that the well samples correspond to thermogenic gases, sourced from organic matter at different maturity levels. These gases indicate deep to shallow migration. On the other hand the gas samples taken from the El Tortero and Caña Brava - Carbonera mines, correspond to humic organic matter sources.

- The C2/C3 vs d13C C3 diagram, suggests that the gas samples analized were originated by primary cracking.

Methodology (What we did)

Review and compilation of organic geochemistry data available in public databases, peer-reviewed papers and EPIS-BIP databases, from 2010 to 2020.

- More than 50000 documents were reviewed, and found around 200 documents and reports with organic geochemistry data.
- Data capturing using excel spreadsheets with the content structure of the 2010 organic geochemistry database, updated with new fields accordingly to the information available on the new references.

Methodology (What we did)

Update the Organic Geochemistry Database of the ANH with the new information found from 2010 to 2020.

- Upload 45447 new records and 427117 data from the excel spreadsheets to the database.
- Create 12 new tables and adding 1337 new fields to the database. (Biomarkers, isotopes, TOC, Pyrolysis, XRD, XRF, vitrinite reflectance).

Methodology (What we did)

Definition of a new content layout for the Organic Geochemistry Atlas of Colombia.

Thematic content 2010:

- Crude Oil Quality
- Depositional Environments
- Chromatograms
- Source Rock Characterization
- Maps (Maturity and Quality)
- Gas Characterization
- Surface Geochemistry
- Petroleum Systems (Crude-Rock Corr)

Added content 2021

- Coal Bed Methane
- Crude Oil Maturity
- Crude Oil Degradation
- Unconventionals
- Piston Cores

Methodology (What we did)

Definition of a new content layout for the Organic Geochemistry Atlas of Colombia.

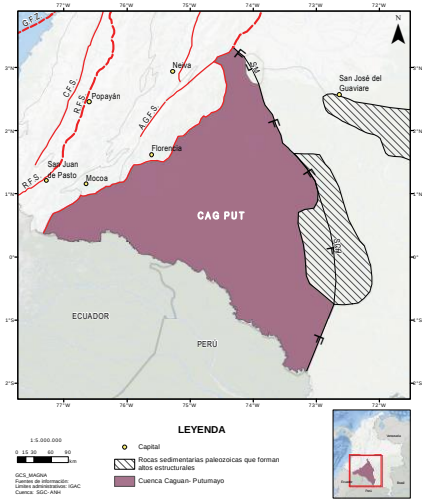
- Atlas 2010 contains 237 graphs and maps for 18 basins.
- Atlas 2021 contains 367 graphs and maps for 19 basins. Including event charts for 15 basins.

English and Spanish versions of the Organic Geochemistry Atlas of Colombia 2021 version.

Content examples

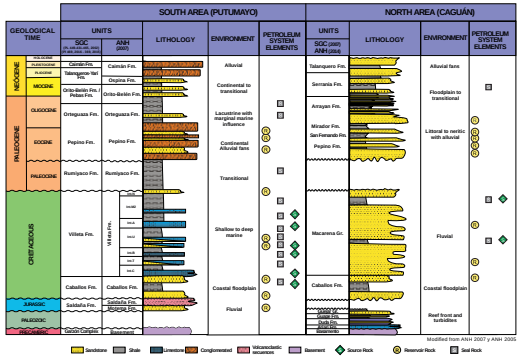
Generalities

Location Map

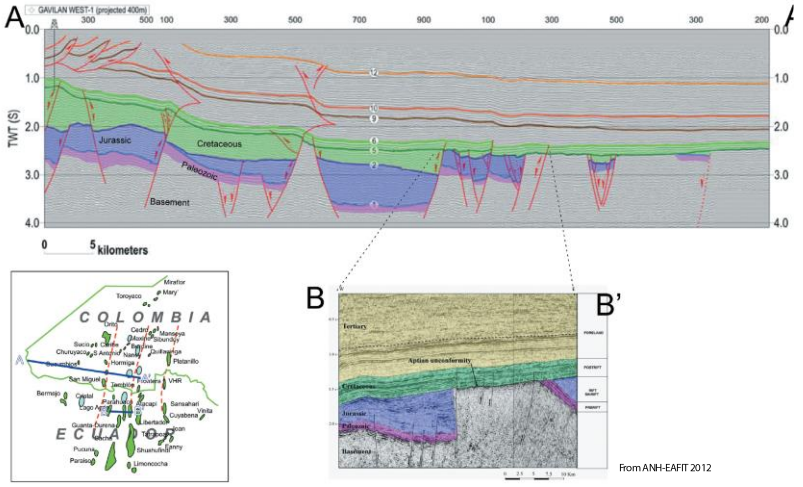


The geochemical data available for the Caguán-Putumayo Basin corresponds with 4698 %TOC and pyrolysis samples, 295 organic petrography samples, 223 crude oil samples with biomarkers, crude bulk, gas and liquid chromatography, and isotopic analyses.

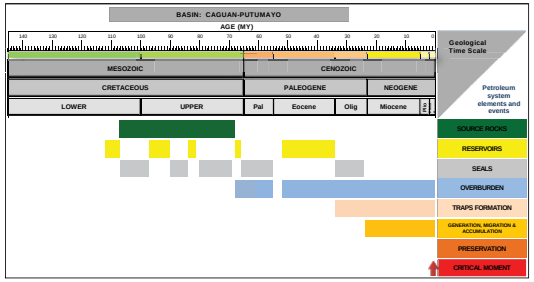
Stratigraphic Column



Structural section

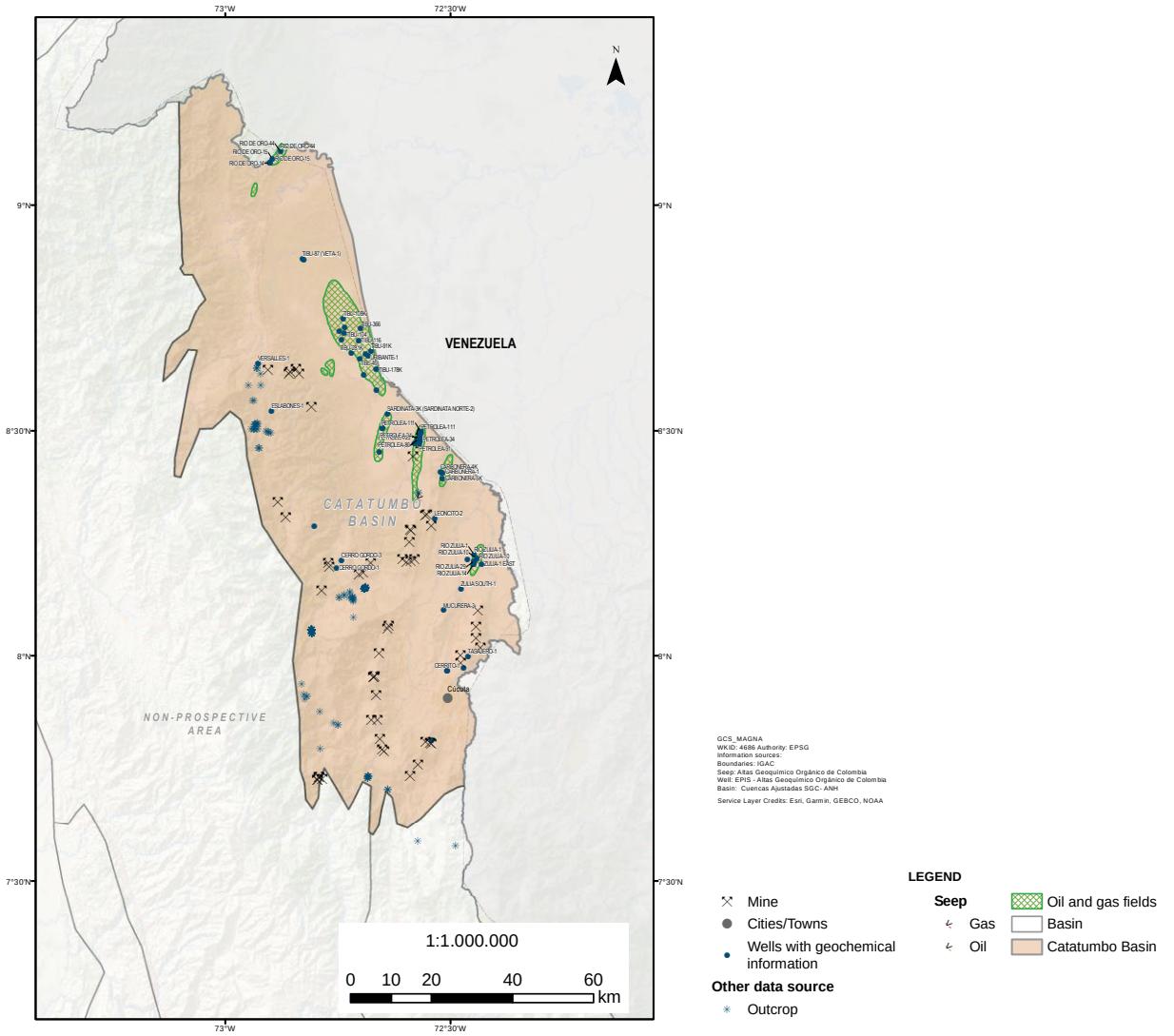


Events Chart



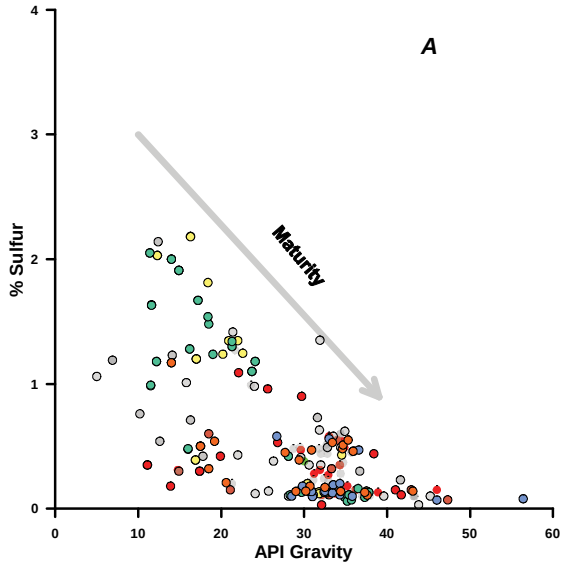
Content examples

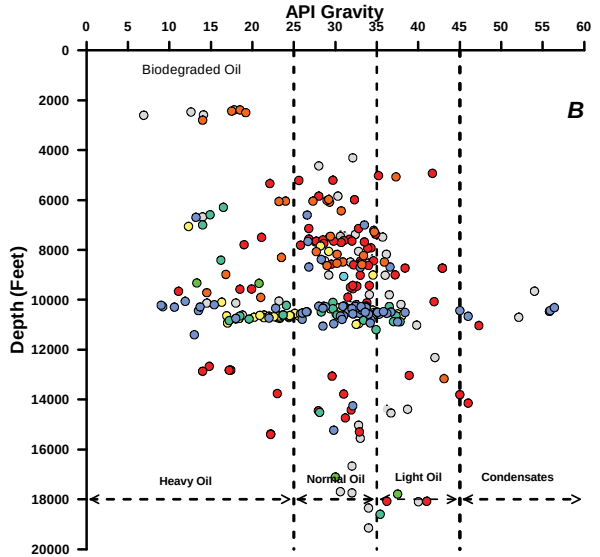
Data Sources



Content examples

Crude Oil Quality





Formation

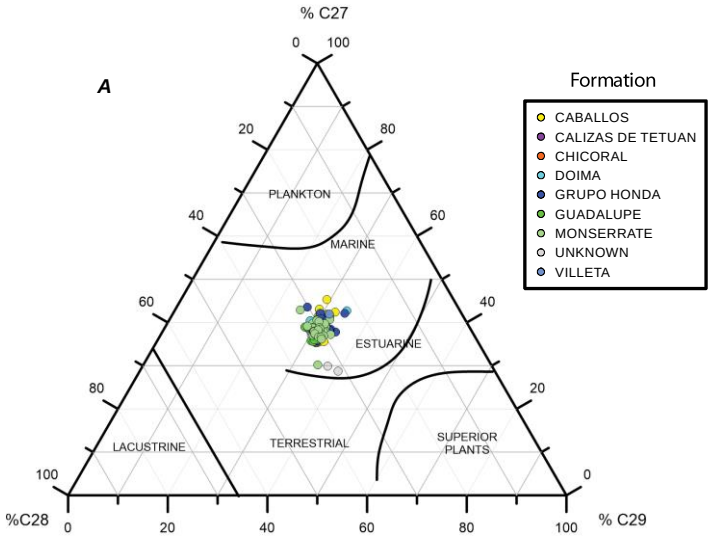
- BARCO
- BARCO - LOS CUERVOS
- CARBONERA
- GACHETA
- GUADALUPE
- MIRADOR
- UNE
- UNKNOWN

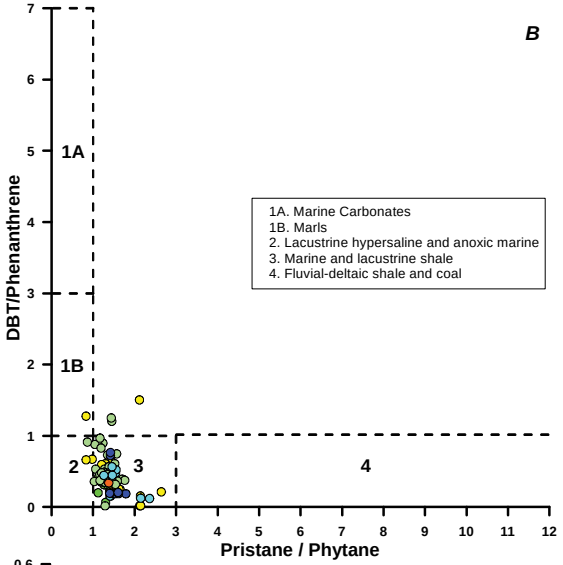
- Heavy and light oils with API gravities ranging from 5° to 50° and sulfur content between 0 and 2.5% are present in the basin. There is no straight relationship between sulfur and API gravity, but oils above 25° API have sulfur values below 1%, and oils below 25° show sulfur content with values up to 2%. This suggests that in the basin there are oils with different thermal maturities and/or different degrees of preservation (biodegradation, water washing, etc.), because crudes having similar API gravities have different sulfur contents, which might indicate that biodegradation is increasing sulfur content and/or reducing API gravity, or different source rocks, considering that oils sourced from shales usually have lower sulfur content than oils from carbonates (Figure A).

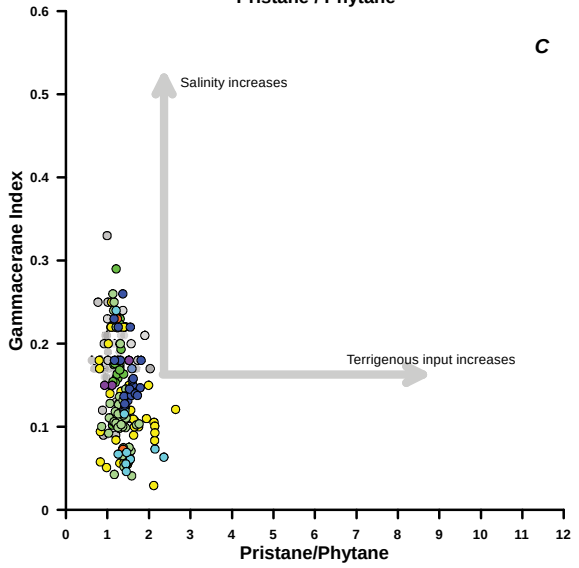
- There is no direct relationship between depth and crude oil quality, indicating that similar quality oils can be found at different stratigraphic levels, probably related to vertical migration along faults. But additionally there is the fact that different API gravity oils can be found at similar depths, reflecting different preservation (biodegradation) and/or thermal maturities (Figure B).

Content examples

Depositional Environments



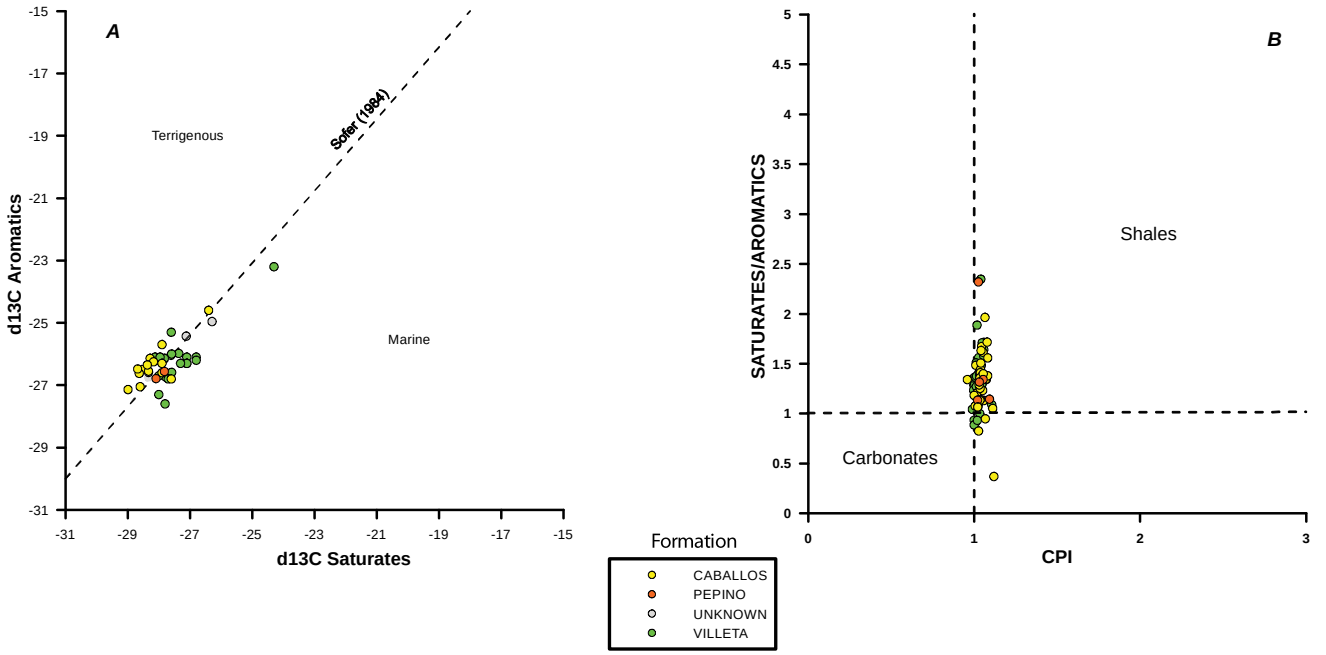




- The steranes ternary plot shows that the oils in the basin were generated from source rocks deposited in estuarine to marine environments (Figure A).
- The DBT/Phenanthrene and Pristane/Phytane ratios show that the oils have been sourced from marine shales with minor input from marls (Figure B).
- The Gammacerane Index and Pr/Ph ratio show that the source rocks were deposited in normal salinity conditions with minor input of terrestrial organic matter (Figure C).

Content examples

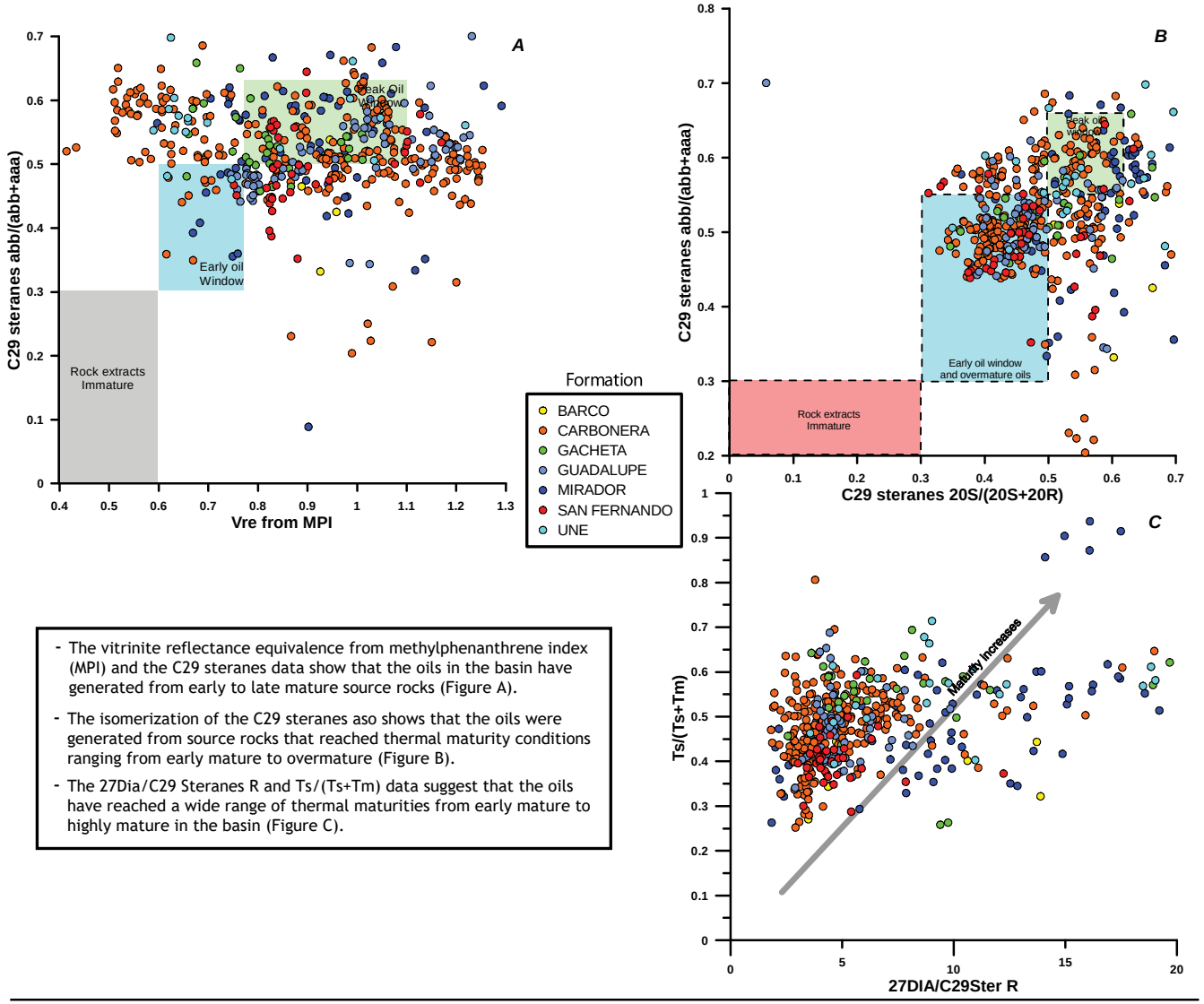
Depositional Environments



- The carbon 13 isotopes from the saturate and aromatic fractions show that the source rocks have input from terrestrial and marine organic matter likely in a transitional environment due to its close proximity with the Sofer Line (Figure A).
- The Carbon Preference Index (CPI) vs Saturates/Aromatics data suggests that the source rocks are mainly shales with minor carbonatic input. (Figure B).
- In summary, the crude oils in the basin correspond predominantly with generating facies deposited in siliciclastic environments ranging from marine to deltaic with an important terrestrial organic matter input. These rocks were deposited during the Cretaceous considering their low oleanane index values corresponding to the Villeta and Caballos formations.
- These crude oils are of good quality with API gravities above 25° and sulfur content below 1% for most of them, and are well preserved (low biodegradation).
- Hydrocarbons have been found in reservoirs corresponding to the Caballos, Villeta and Macarena formations of Cretaceous age and the Cenozoic Pepino and Rumiyaco formations.

Content examples

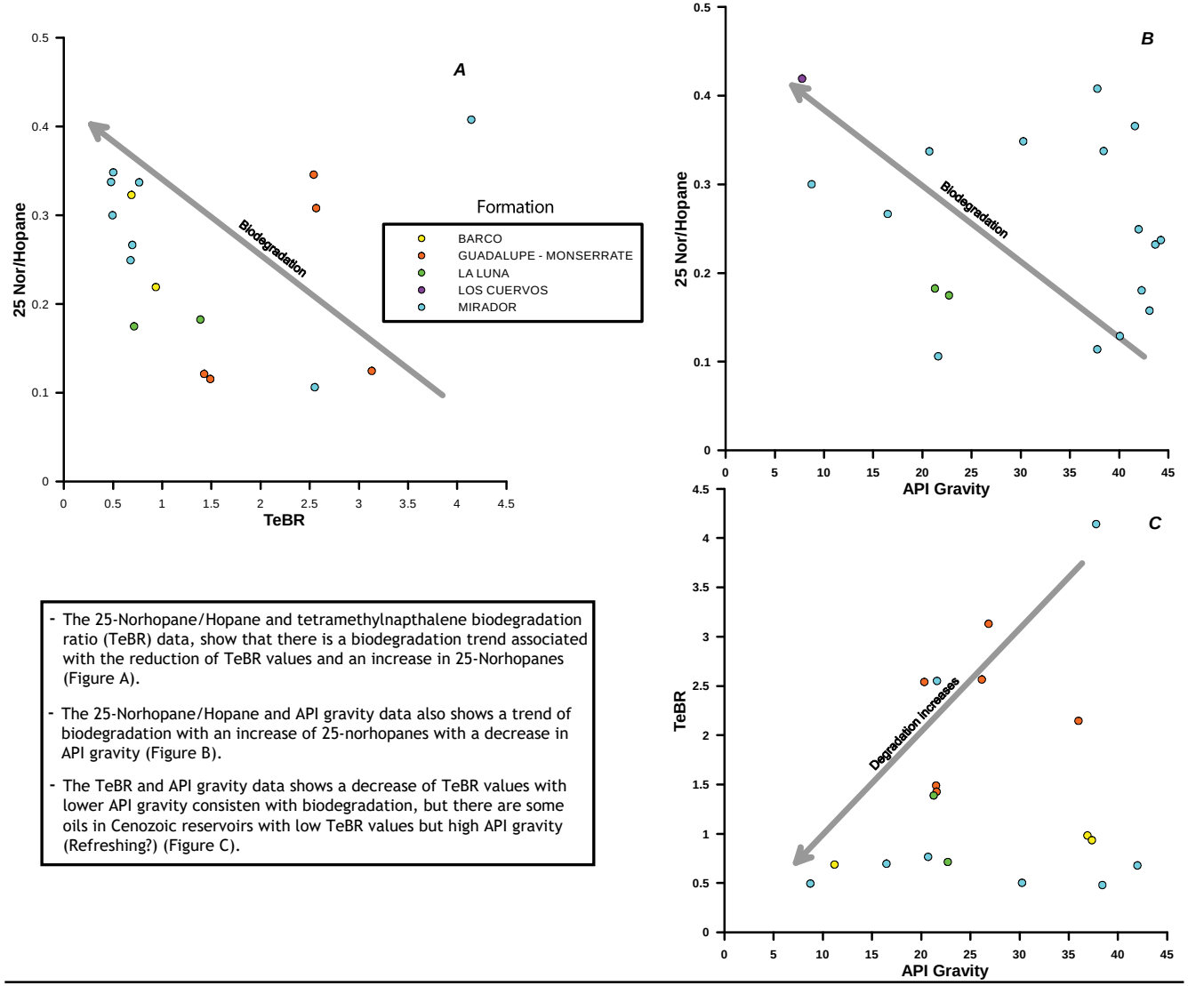
Crude Oil Maturity



- The vitrinite reflectance equivalence from methylphenanthrene index (MPI) and the C29 steranes data show that the oils in the basin have generated from early to late mature source rocks (Figure A).
- The isomerization of the C29 steranes aso shows that the oils were generated from source rocks that reached thermal maturity conditions ranging from early mature to overmature (Figure B).
- The 27Dia/C29 Steranes R and Ts/(Ts+Tm) data suggest that the oils have reached a wide range of thermal maturities from early mature to highly mature in the basin (Figure C).

Content examples

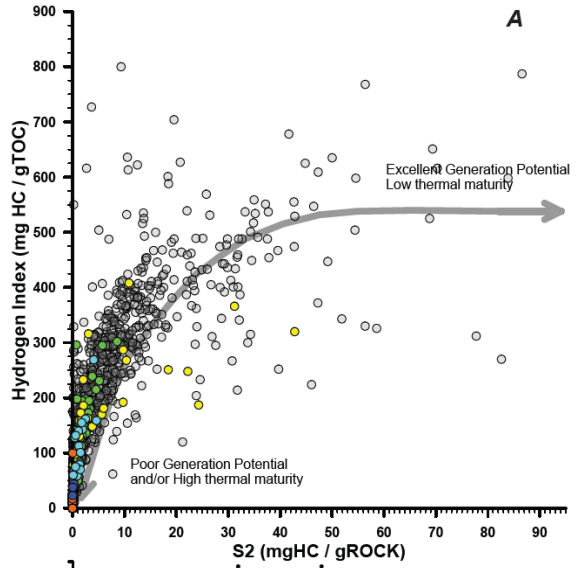
Crude Oil Degradation

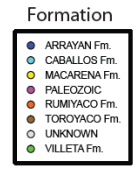


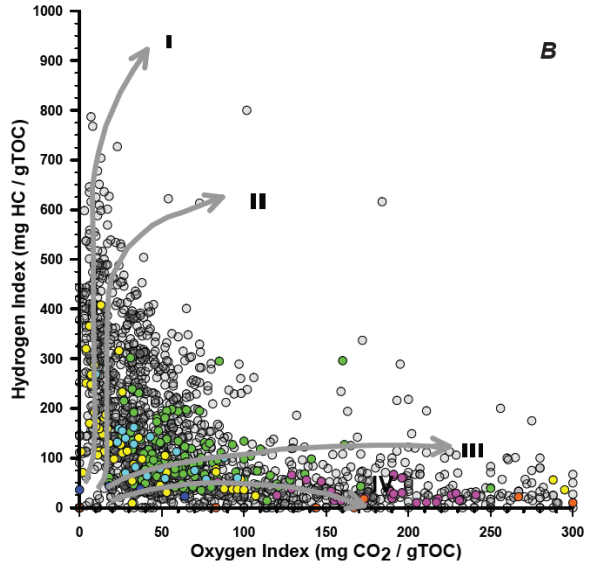
- The 25-Norhopane/Hopane and tetramethylnapthalene biodegradation ratio (TeBR) data, show that there is a biodegradation trend associated with the reduction of TeBR values and an increase in 25-Norhopanes (Figure A).
- The 25-Norhopane/Hopane and API gravity data also shows a trend of biodegradation with an increase of 25-norhopanes with a decrease in API gravity (Figure B).
- The TeBR and API gravity data shows a decrease of TeBR values with lower API gravity consisten with biodegradation, but there are some oils in Cenozoic reservoirs with low TeBR values but high API gravity (Refreshing?) (Figure C).

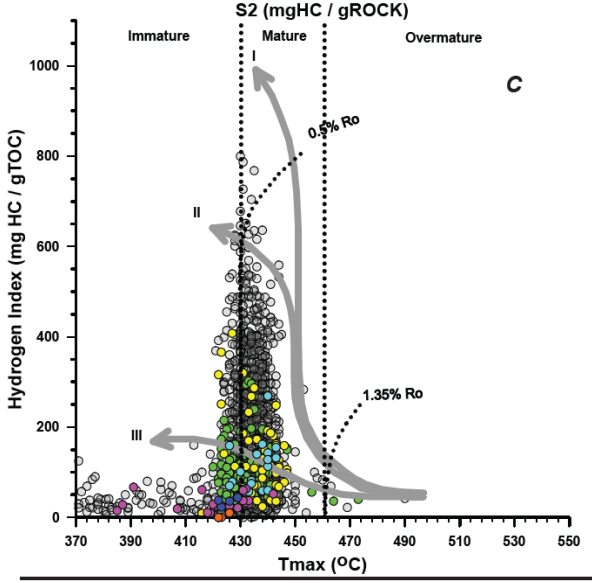
Content examples

Source Rock Characterization









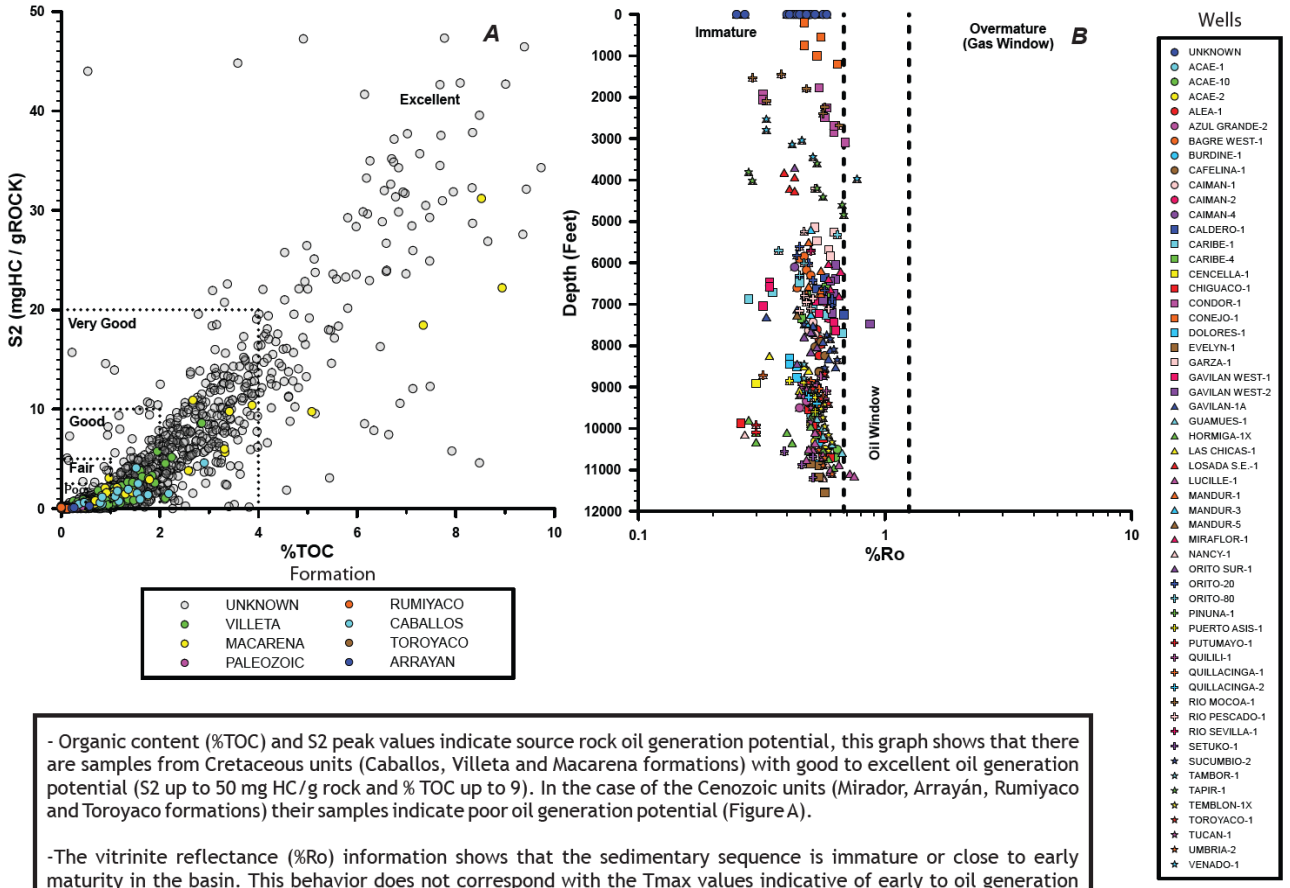
- The data obtained from pyrolysis Rock-Eval of rock samples for Hydrogen Index (HI) and S2 peak, indicate that samples from the Cretaceous Caballos, Villeta and Macarena formations have good generation potential (HI > 200mg HC/g TOC and S2 > 5 mg HC/g rock). Taking into account that these units are deeply buried in the basin, the poor generation values obtained from some samples could reflect the depletion effect caused by the high thermal maturity of these rocks. The data also indicate that the Cenozoic rocks (Mirador, Rumiyaco and Toroyaco formations) all have poor generation potential (Figure A).

- The Oxygen Index vs Hydrogen Index diagram (Van Krevelen diagram) shows that rock samples from the Cretaceous Caballos, Villeta and Macarena formations have type II oil-prone kerogen. There are also samples from these formations with type III gas-prone characteristics. In the case of the Cenozoic units (Mirador, Arrayán, Rumiyaco and Toroyaco formations) their samples are indicative of type III gas-prone kerogen to type IV kerogen. The Paleozoic samples have very low HI values and correspond mainly with type IV kerogen (Figure B).

- The Tmax maturity parameter vs Hydrogen Index graph shows that many samples from the Cretaceous to Cenozoic units mentioned, have reached early maturity to oil generation peak conditions in the basin (Figure C).

Content examples

Source Rock Characterization



- Organic content (%TOC) and S2 peak values indicate source rock oil generation potential, this graph shows that there are samples from Cretaceous units (Caballos, Villeta and Macarena formations) with good to excellent oil generation potential (S2 up to 50 mg HC/g rock and % TOC up to 9). In the case of the Cenozoic units (Mirador, Arrayán, Rumiyaco and Toroyaco formations) their samples indicate poor oil generation potential (Figure A).

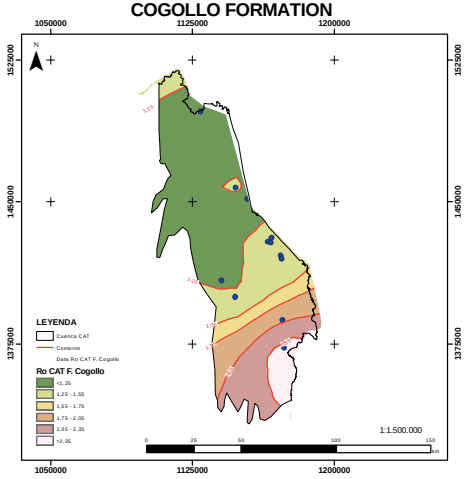
-The vitrinite reflectance (%Ro) information shows that the sedimentary sequence is immature or close to early maturity in the basin. This behavior does not correspond with the Tmax values indicative of early to oil generation peak, and would not explain the oil accumulations and crude oil quality found in the basin (Figure B).

-In summary, the best source rocks at the basin, with good to excellent oil generation potential intervals are the Cretaceous rocks of the Caballos, Villeta and Macarena formations. The Cenozoic rocks of the Mirador, Arrayán, Rumiyaco and Toroyaco formations have poor oil generation potential. Tmax maturity data indicates that the Cretaceous oil-prone formations are mature and the sources for the hydrocarbons in the basin.

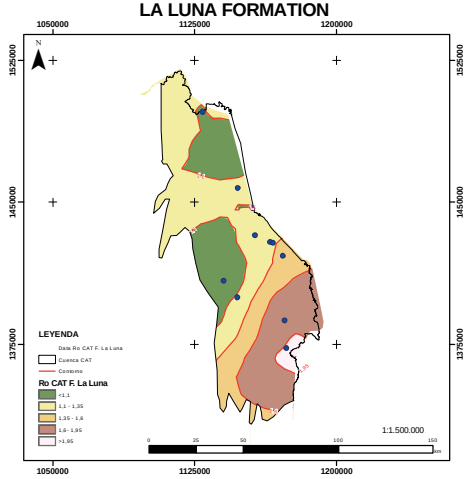
Content examples

Source Rock Quality and Maturity Maps - Vitrinite Reflectance

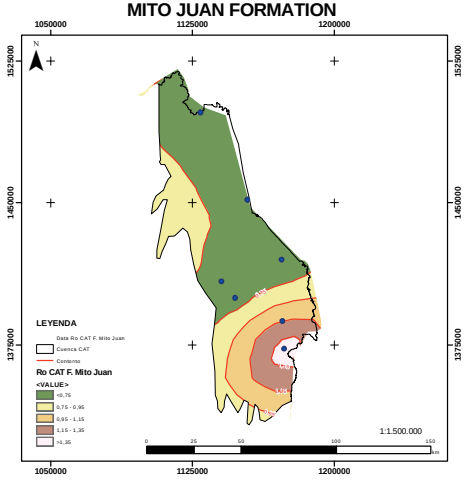
COGOLLO FORMATION



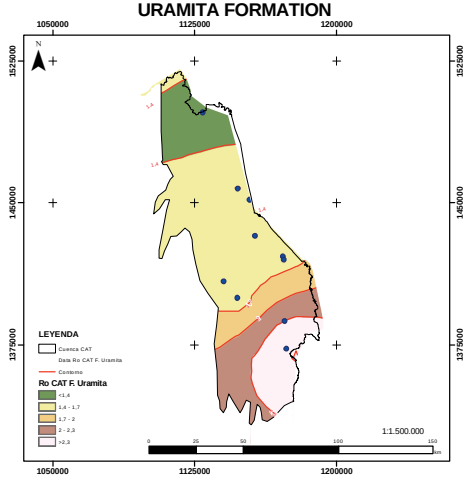
LA LUNA FORMATION



MITO JUAN FORMATION

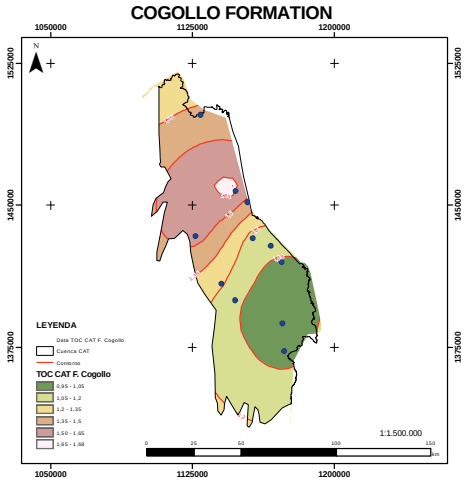


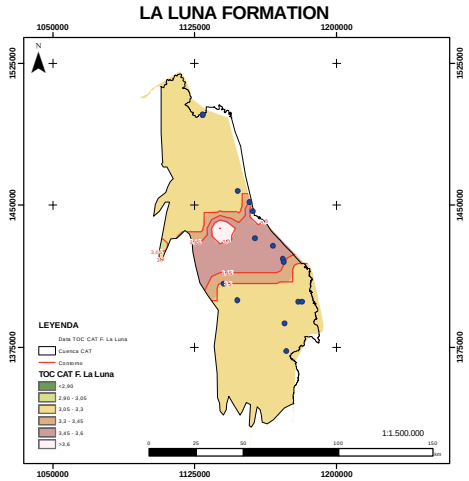
URAMITA FORMATION

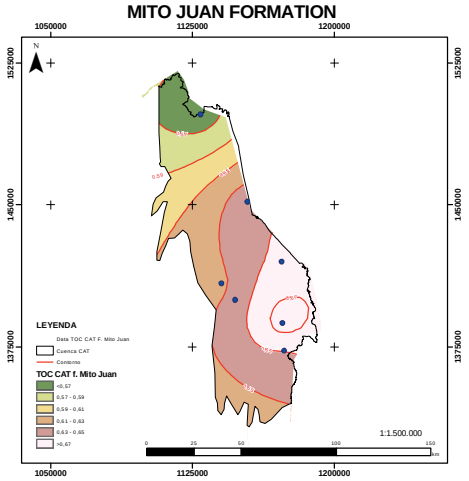


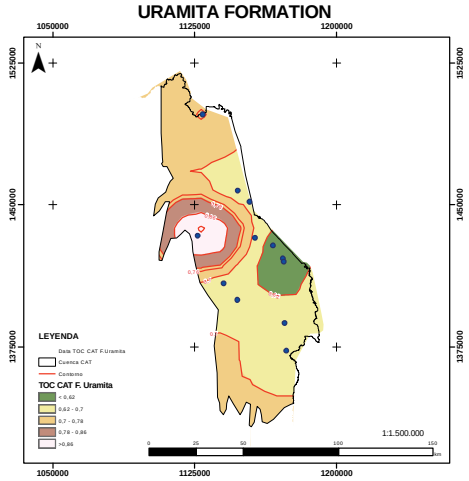
Content examples

Source Rock Quality and Maturity Maps - %TOC



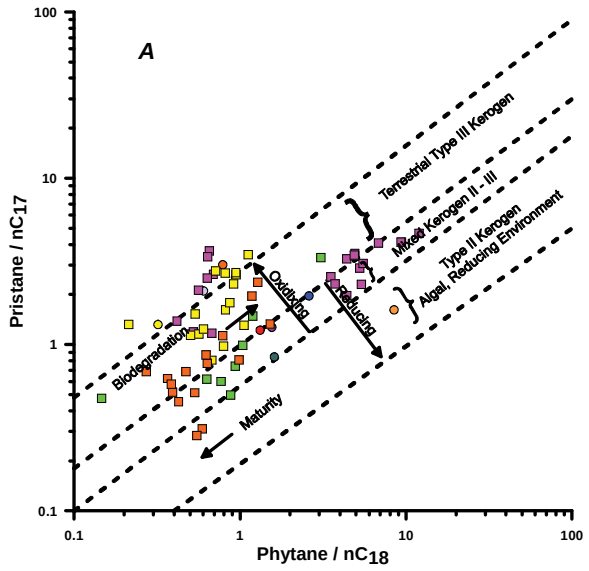


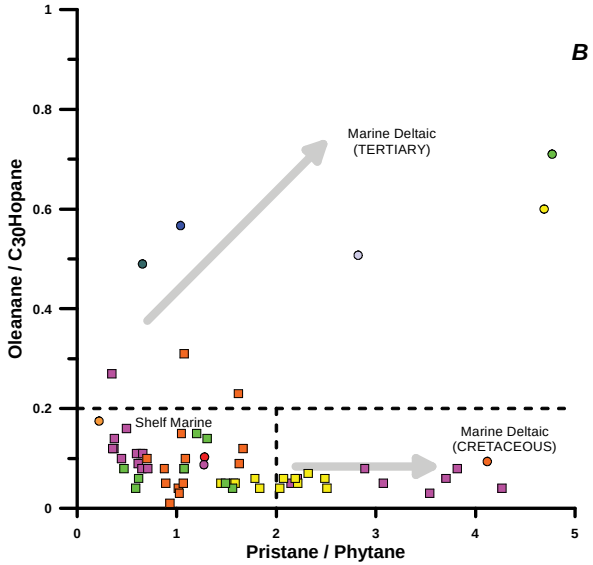




Content examples

Petroleum Systems (Crude - Rock Correlations)





Legend

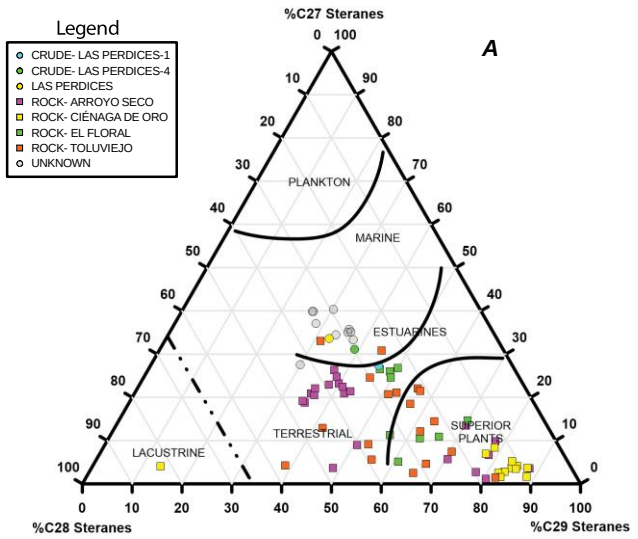
- CRUDE- PERDICES Nº 9
- CRUDE LAS PERDICES-1
- CRUDE- LAS PERDICES-4
- CRUDE- FLORESANTO-6
- CRUDE- SAN SEBASTIAN Nº 3
- CRUDE- SAN SEBASTIAN Nº 2
- CRUDE- SAN SEBASTIAN Nº 1
- CRUDE- PERDICES Nº 10
- CRUDE- PERDICES Nº 8
- CRUDE- RÍO SINÚ Nº 4
- ROCK- ARROYO SECO Fm.
- ROCK- CIÉNAGA DE ORO Fm.
- ROCK- EL FLORAL Fm.
- ROCK- TOLUVIEJO Fm.

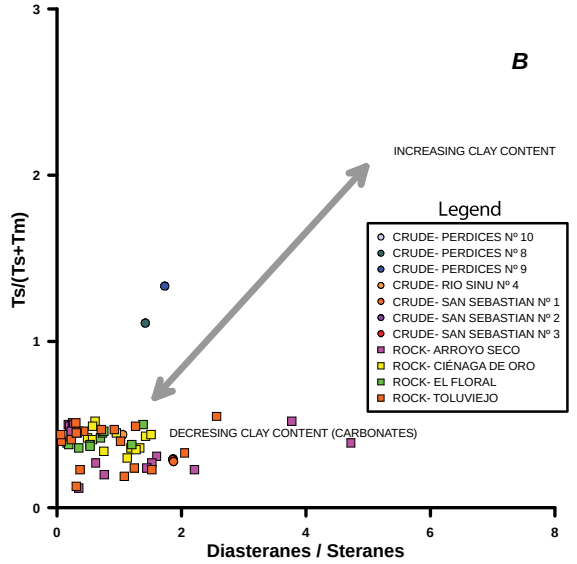
- The Pristane/Phytane vs Oleanane/C30 Hopane (Oleanane Index) graph shows that oils from the San Sebastián-3, San Sebastián-2 and Río Sinú-4 wells have low oleanane index values (<0.2) and Pr/Ph values (<2), and correlate well with rock extracts from the Arroyo Seco Toluviejo and El Flora formationsl, suggesting that these units are the sources for the hydrocarbons found in those wells. The oil from the San Sebastián-1 well has higher Pr/Ph value (>4) and seems to correlate well with rock extracts from the Arroyo Seco Formation (Figure A).

- The Phytane/nC18 vs Pristane/nC17 graph shows good correlation between the crude oils found in the San Sebastián-1, San Sebastián-3, Perdices-10 and Floresanto-6 wells with rock extracts from samples of the Arroyo Seco, Ciénaga de Oro, El Floral and Toluviejo formations. Indicating that the oils have origin from terrestrial organic matter and to a minor extent from mixed kerogen (type II-III), but additionally that the crudes and rocks have similar thermal maturities (Figure B).

Petroleum Systems (Crude - Rock Correlations)

Content examples





The diasteranes/steranes vs Ts/(Ts+Tm) graph shows that the oils and rock extracts were generated from poor-clay rocks.

There is few crude and extracts information available for the basin, however some preliminary conclusions on the possible petroleum systems active at the basin can be obtained from this data.

- The extracts from the Tertiary formations (Arroyo Seco, Ciénaga de Oro, El Floral and Toluviejo) have low oleanane index values (< 0.2), indicative of low terrestrial organic matter input from angiosperms.

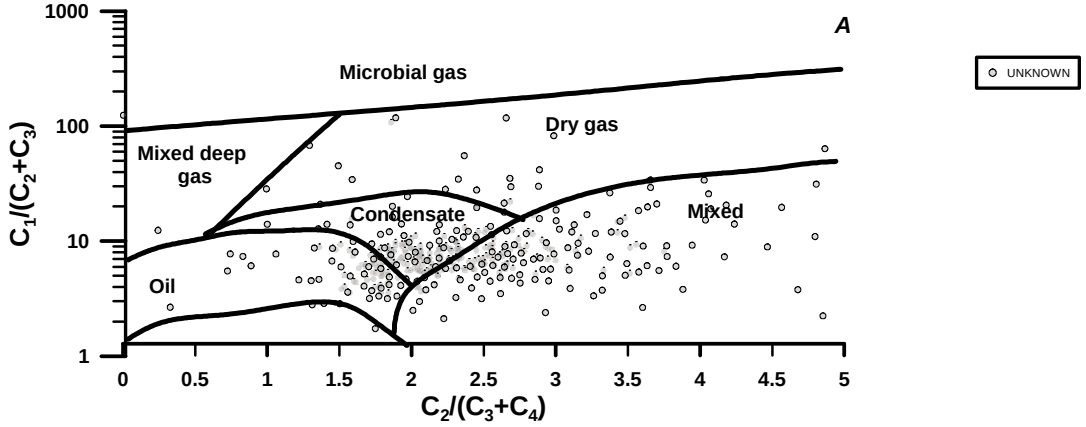
- Most of the crudes in the basin have high olenanane index values (> 0.4), and high values of this index are indicative of high terrestrial organic matter input and/or Tertiary age of the source rocks (Peters and Moldowan, 1993).

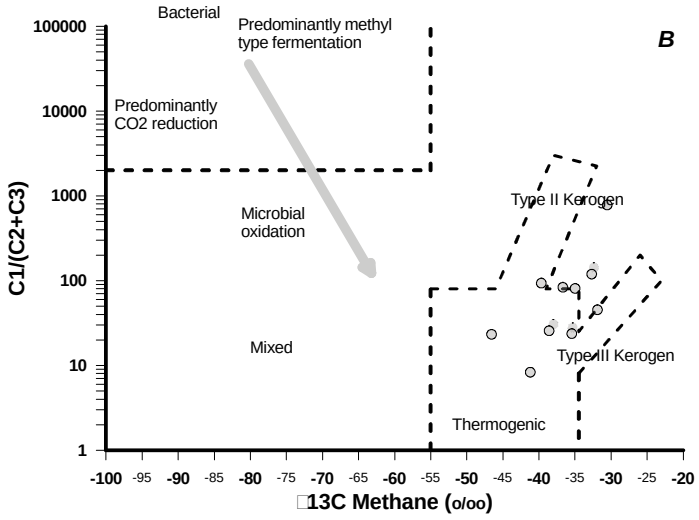
- Some crude oils correlate with the low oleanane extracts of the Tertiary formations, suggesting that these units could be the sources for those oils, particularly those with Pristane/Phytane < 2 (Arroyo Seco and El Floral formations).

- From the existing information at the basin some hypothetical petroleum systems can be postulated: Arroyo Seco (.), Arroyo Seco –Chengue (.), Arroyo Seco – Toluviejo (.), Arroyo Seco – Ciénaga de Oro (.), Toluviejo (.), Toluviejo – Chengue (.), Toluviejo – Ciénaga de Oro (.), Ciénaga de Oro (.).

Surface Geochemistry

Content examples





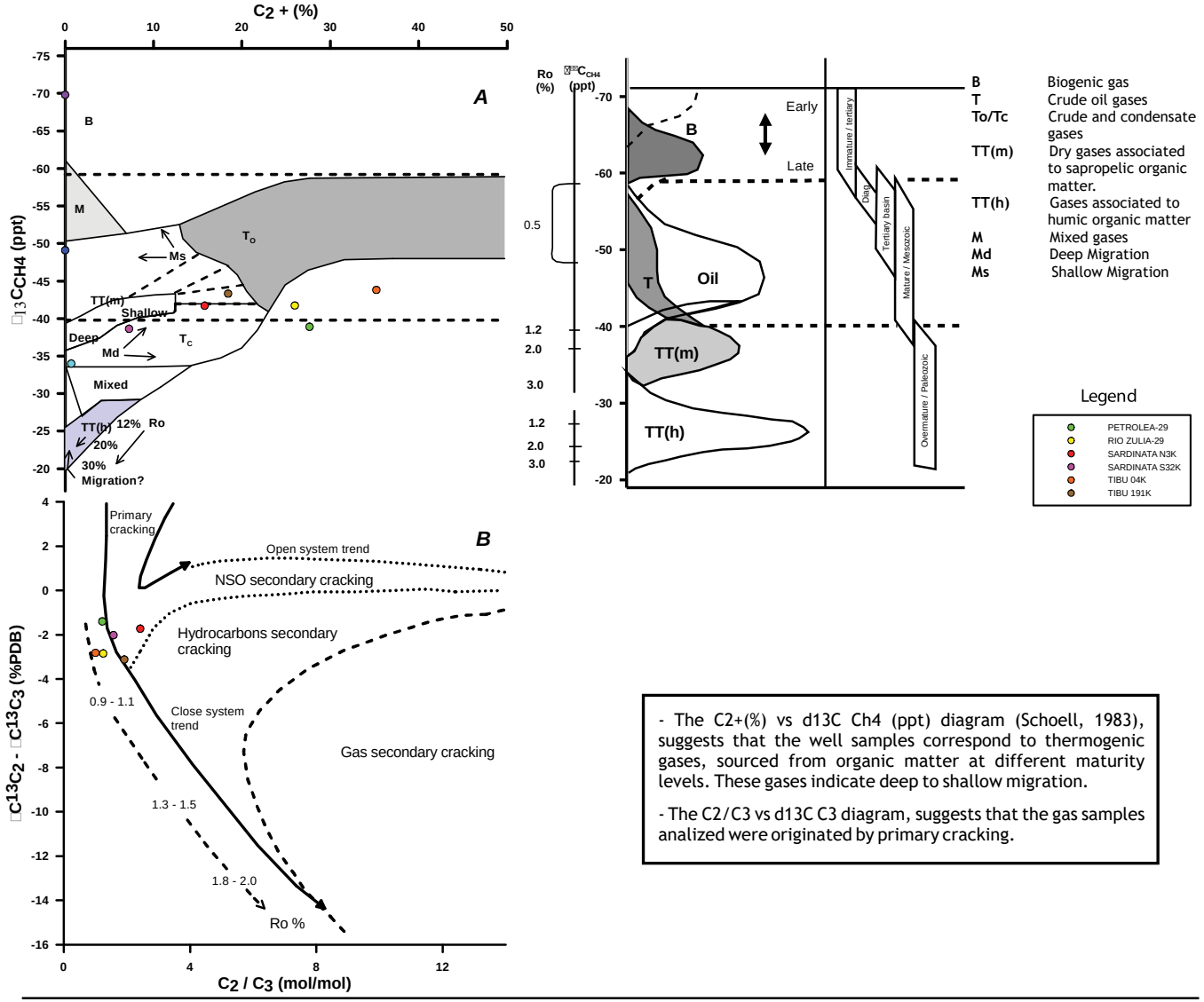
Compositional data from surface geochemistry samples indicate that hydrocarbons are thermogenic, formed mainly during late oil generation window (condensates) with minor presence of high maturity hydrocarbons (gas generation window) with some mixing between different thermal maturity hydrocarbons.

Isotopic data indicates thermogenic generation from probably type II and type III kerogens

There is no evidence of microbial gas in the basin.

Content examples

Gas Characterization

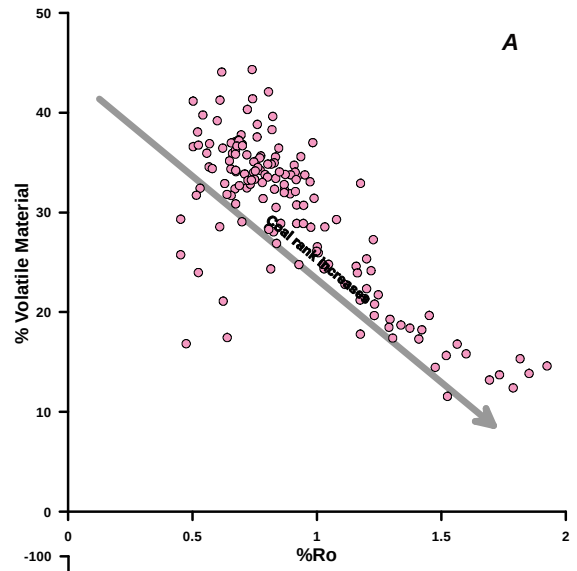


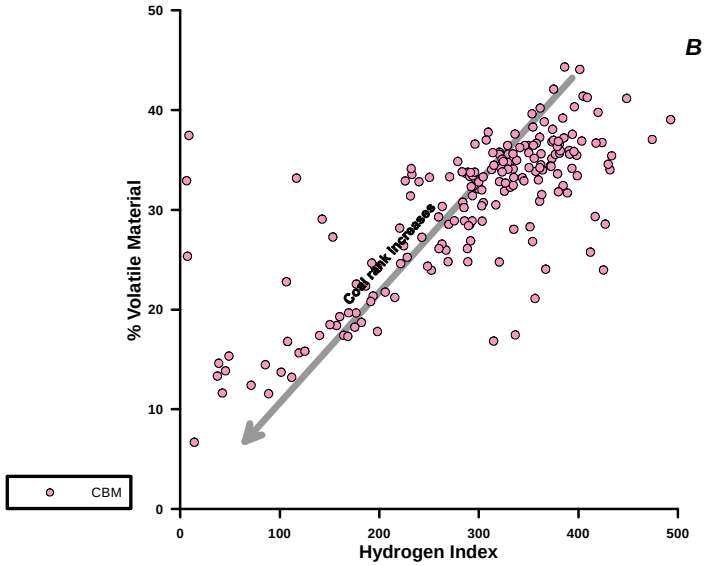
- The C2+(%) vs d13C Ch4 (ppt) diagram (Schoell, 1983), suggests that the well samples correspond to thermogenic gases, sourced from organic matter at different maturity levels. These gases indicate deep to shallow migration.

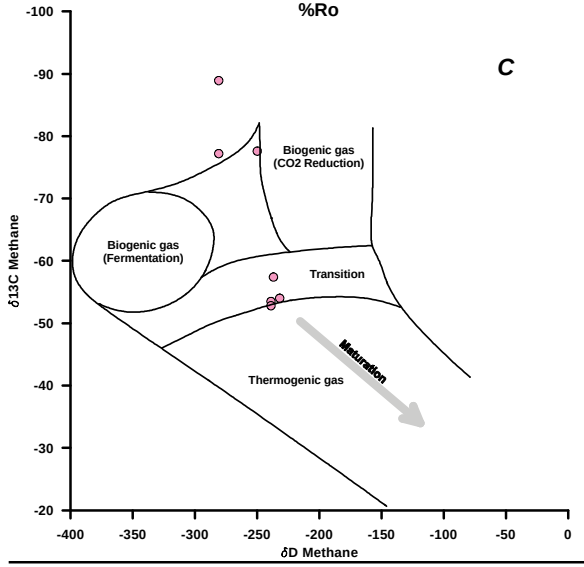
- The C2/C3 vs d13C C3 diagram, suggests that the gas samples analized were originated by primary cracking.

Content examples

Coal Bed Methane





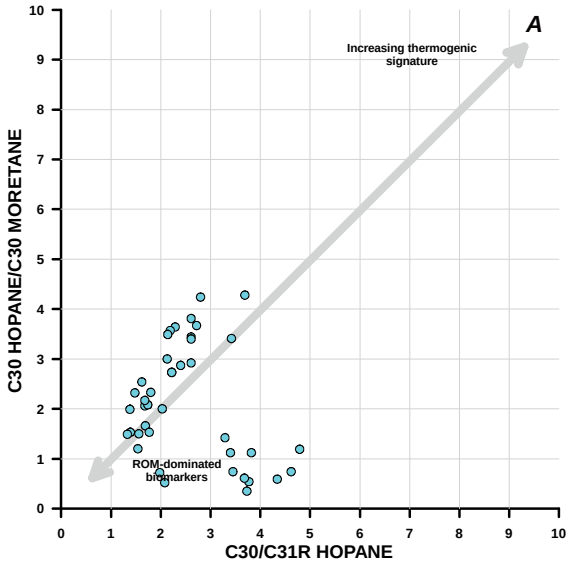


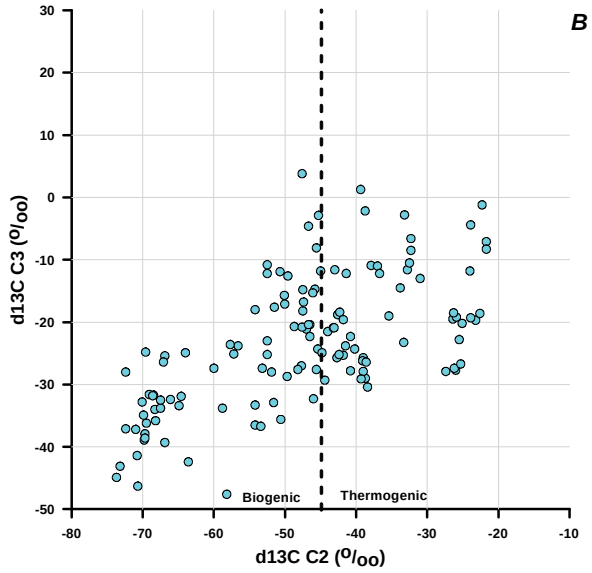
- The data available from coal seams at the Cordillera Basin show a trend relating the volatile material with the coal rank, being the higher the rank the lower the volatile material in the samples (Figure A). A direct relation can be seen from the hydrogen index and volatile material data, in this case a the lower the hydrogen index, the lower the volatile material in the coal (Figure B).

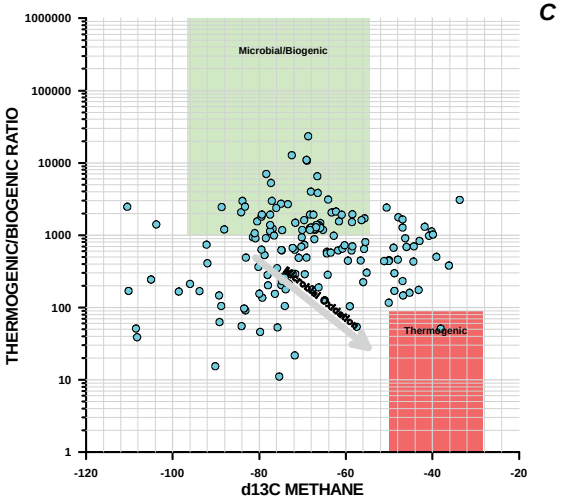
  The dD-d13C of methane isotopes data, show that the gas is biogenic in origin with a transition to thermogenic in higher rank coals, being the gas produced by CO2 reduction processes (Figure C).

Piston Cores

Content examples



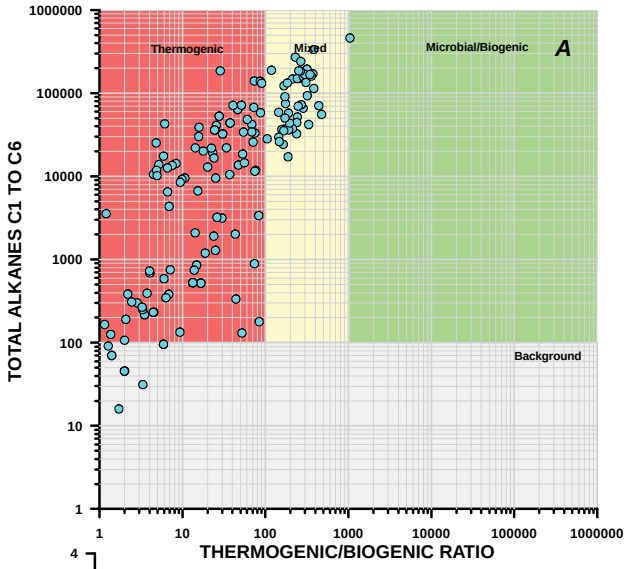


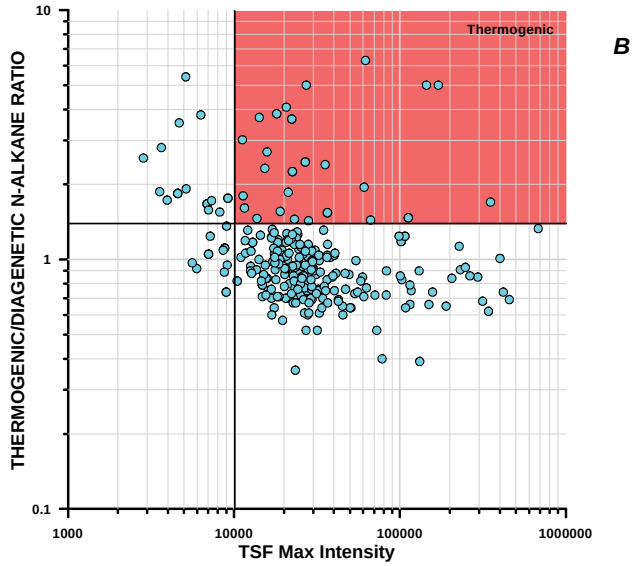


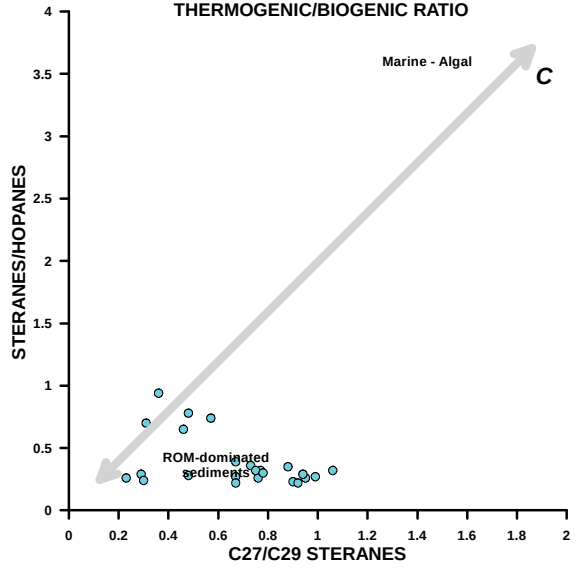
- The C30/C31R hopane and C30 hopane/C30 Moretane data also suggests a biogenic origin or alteration of the hydrocarbons due to recent organic matter presence in the piston cores (Figure A).
- The C13 isotopic data from C2 show that biogenic and thermogenic origin of the gases are possible in the basin (Figure B).
- The thermogenic/biogenic ratio C13 isotopic data of methane suggests a biogenic origin for multiple samples in the basin, however many samples are present in between the thermogenic and biogenic origins with the ratio and isotopic values altered by microbial oxidation, something also suggested by the ROM biomakers (Figure C).
- The total alkanes C1-C6 and carbon isotopic data, along the T/B ratio suggests the possible existence of thermogenic hydrocarbons at the Colombia Basin, but the presence of ROM biomarkers also indicates that there is the possibility of alteration by biogenic processes of the thermogenic signature. So far the data suggests that biogenic and thermogenic origins for hydrocarbons can not be ruled out.

Content examples

Piston Cores



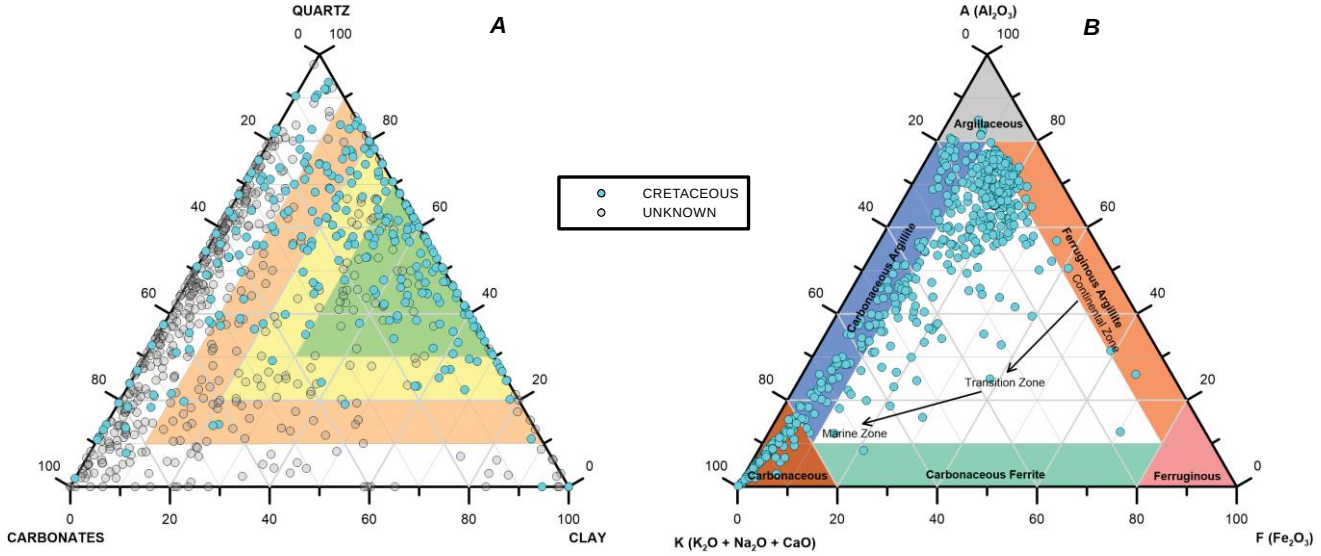




- The thermogenic/biogenic ratio and total alkanes C1-C6 data show that most of samples in the basin could have a thermogenic origin (Figure A).
- The Total Fluorescence (TSF) max intensity of the piston core samples along with the thermogenic-diagenetic ratio suggests also that some samples could of thermogenic origin, however most samples are outside the thermogenic range (Figure B).
- The C27C29 Steranes and steranes/hopanes data indicate that the hydrocarbons found in the piston cores might have origin from recent organic matter (ROM) or ROM contamination of biogenically altered organic matter (Figure C).

Unconventionals - Source Rock Reservoirs

Content examples

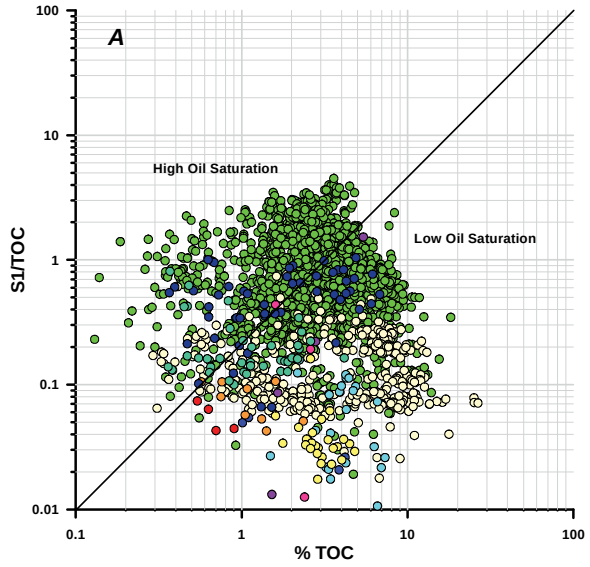


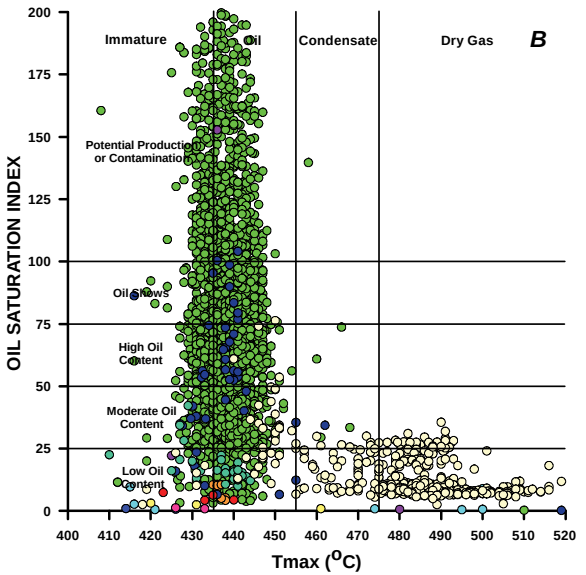
The quartz-carbonates-clay ternary plot indicates that most samples although in the brittle domain favourable for fracing, are located outside the green triangle, in which the proportions of the minerals are better not only for fracing but also for organic matter preservation for hydrocarbons generation, in this case most samples lie outside this area and could be considered as less favourable for unconventionals prospectivity. However it is important to notice that there is no systematic sampling of the Cretaceous rocks precluding a better interpretation of the data (Figure A).

The AKF ternary plot shows that the samples range from argillaceous to carbonaceous composition indicating that mainly shales and calcareous rocks comprise the intervals studied for unconventionals, being the more carbonaceous the more interesting intervals for fracing in the basin (Figure B).

Content examples

Unconventionals - Source Rock Reservoirs





Formation

- FRONTERA
- HILO
- LA CIRA SHALE
- LA LUNA
- PAJA
- PAJA-TABLAZO
- REAL GR
- SIMITI
- SOCOTÁ SUPERIOR
- TABLAZO
- UMIR

- The %TOC and S1/TOC data show a high dispersion with samples in the high saturation and low saturation areas. In the high saturation area are mainly samples from La Luna Formation, while in the low saturation area there are samples from older rocks of the Paja, Tablazo, Simití and Socotá formations, which are mainly depleted for oil in the basin (Figure A).
- The Oil Saturation Index (OSI) and Tmax data show that the Paja and Tablazo formations are in the condensate to dry gas realms which make them more favorauble for shale gas, meanwhile La Luna is in the immature to oil realms which make this unit more likely for shale oil (Figure B).

Concluding Remarks

- During the project, the organic geochemistry database and Organic Geochemistry Atlas of Colombia, were significantly updated not only with data useful for conventional exploration, but also for unconventionals resources exploration, including CBM and Source Rock Reservoirs and piston cores data.
- Additional information on crude oils and oilseeps acquired mainly by the ANH in the last ten years, has provided data for a better characterization of the crude oils found in the colombian basins, particularly their thermal maturity and preservation.
- In general there is a lack of data from rock extracts for better characterization of the petroleum systems.

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Thank You