

New Findings on Petroleum Exploration in the Palaeozoic of the Llanos Basin

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SERVICIO
GEOLÓGICO
COLOMBIANO



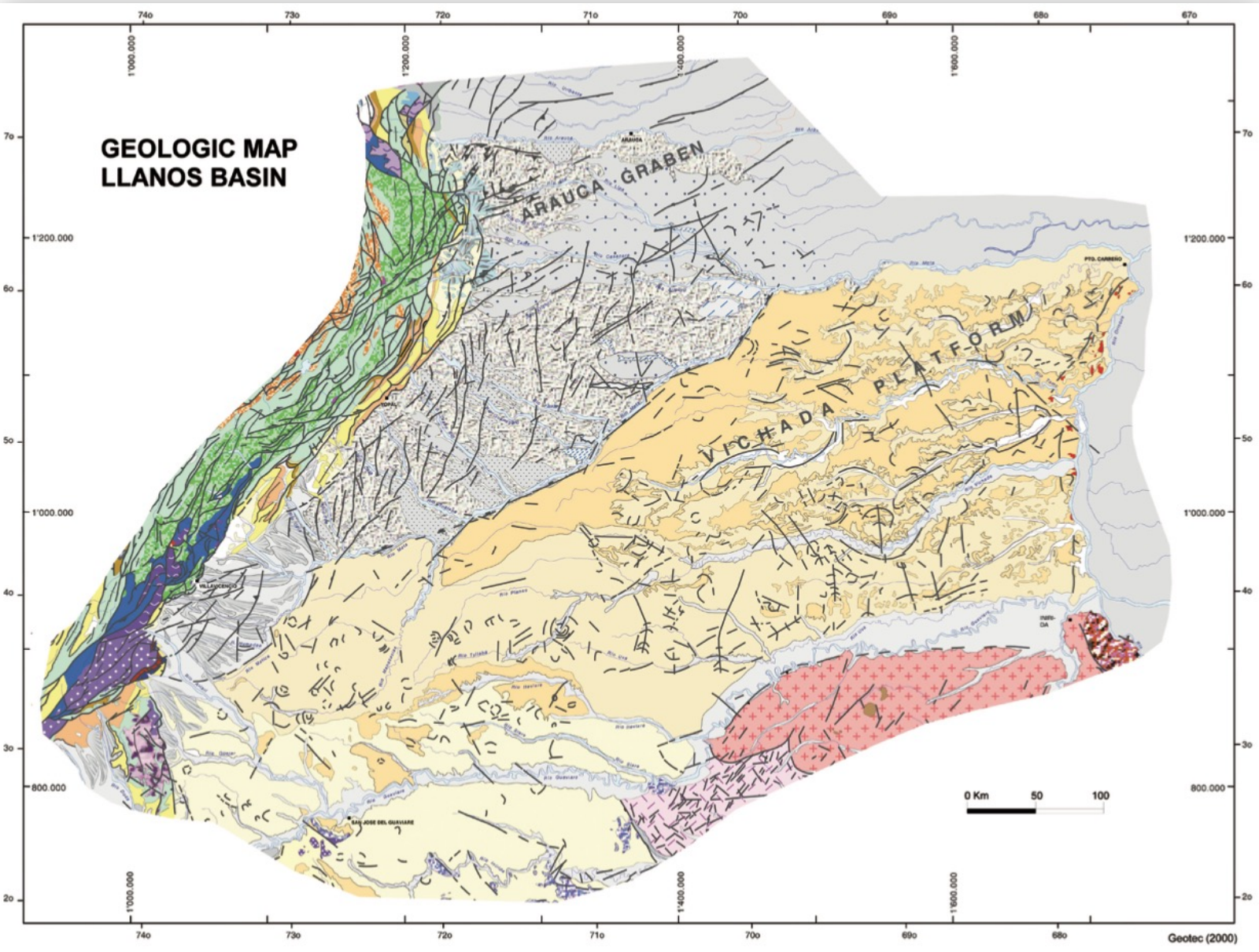
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COLOMBIA



El futuro
es de todos

Minenergía

GEOLOGIC MAP LLANOS BASIN



What is this project about?

Is there a Petroleum system in Pz-Pz or Pz-K/T or K/T-Pz?



- Oil and Gas industry started in 1918 in Colombia, since then the interest has been mainly in the last 145 million years
- Palaeozoic is about 290 million years, twice the time from Cretaceous to today.
- However, the Palaeozoic is still unknown

In the north of South America the Oil and Gas production comes from petroleum systems Cretaceous-Tertiary

The history of exploration and generation of knowledge in Colombia has been focused in these periods of the geologic time

The Palaeozoic has kept as a frontier exploration. The biggest amount of wells are stopped and the top of Palaeozoic

A big mistake of the industry has been declared Palaeozoic as “Economic Basement”



Figura 1. Mapa de ubicación de las Cuencas Andinas tratadas en este volumen. Gráficos estadísticos modificados de Rosso

Is There a Petroleum System Pz-Pz or Pz-K/T ?

Elements of a Conventional Petroleum System

- Source Rock *
- Seal Rock
- Reservoir rock
- Overburden rock

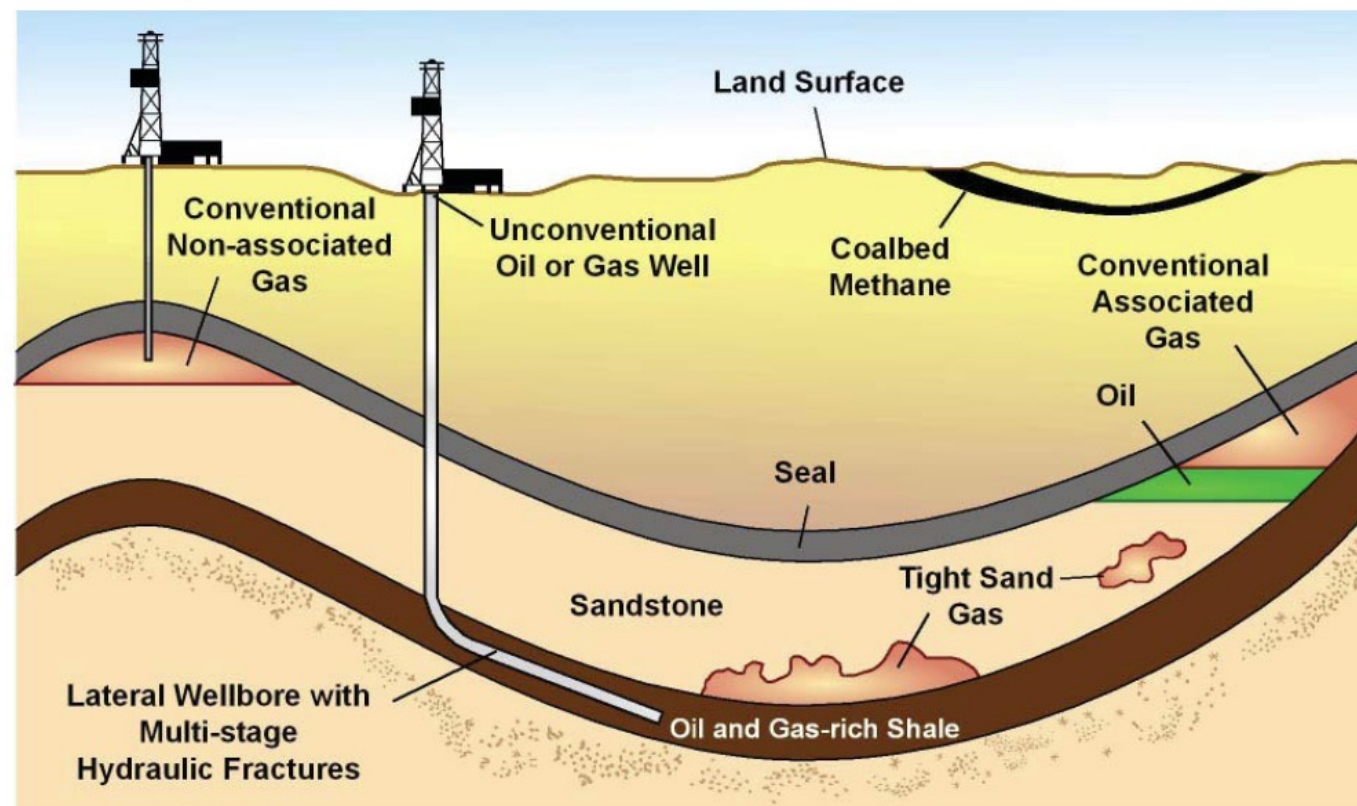
Processes

- Trap Formation
- Generation* - Migration - Accumulation

“The elements and processes must be correctly placed in time and space...”

* Unconventional

The Geology of Conventional and Unconventional Oil and Gas

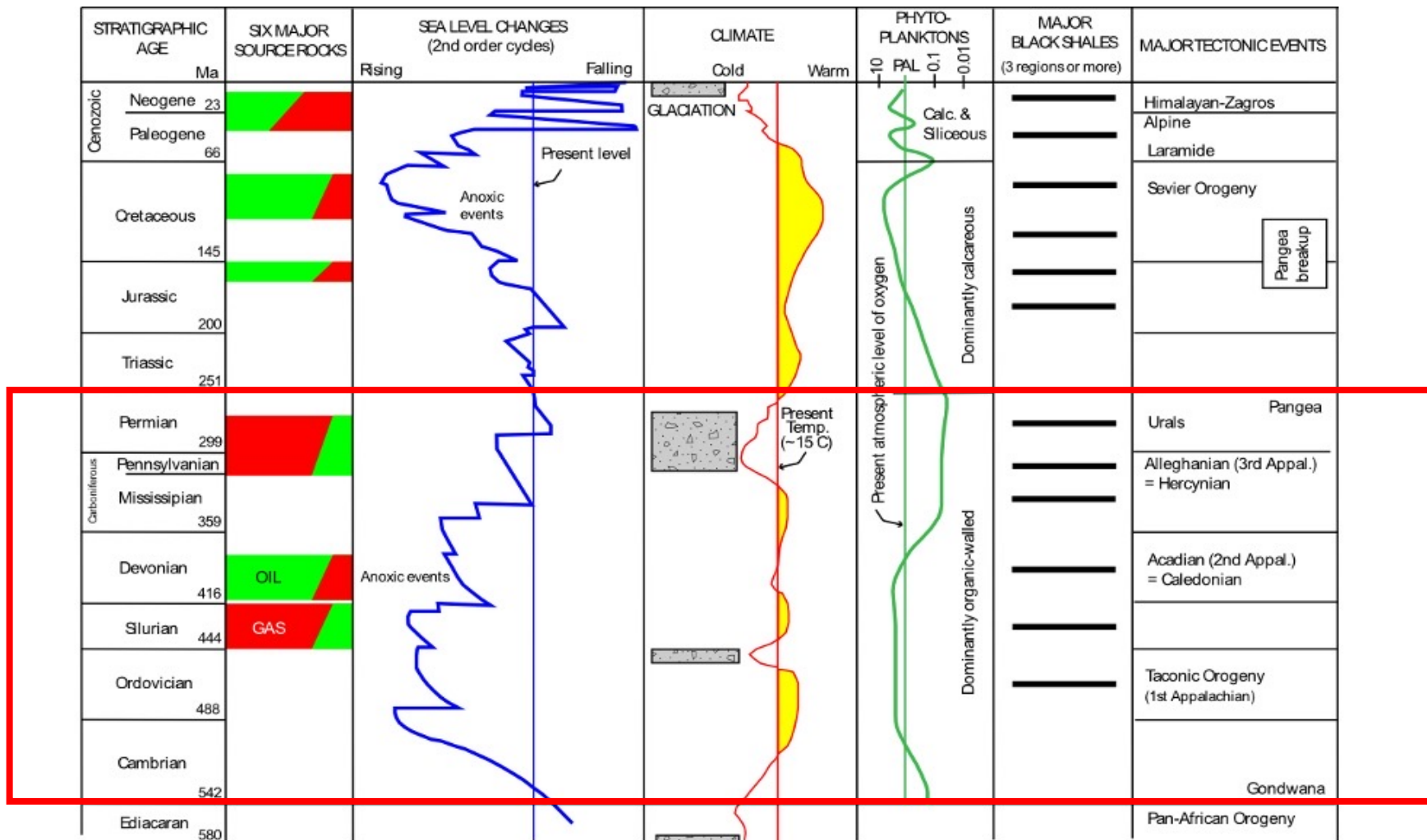


Source: EIA

Silurian (444-416 Ma)
Late Devonian (385-360 Ma)
Pennsylvanian – Late Permian (318-270 Ma)
Late Jurassic (165-145 Ma)
Mid Cretaceous (125-89 Ma)
Oligocene - Miocene (34-5 Ma)

34% Phanerozoic time

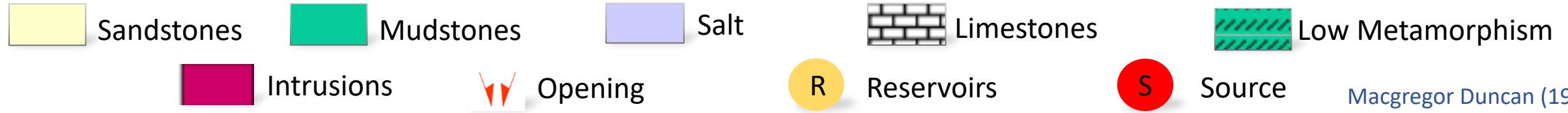
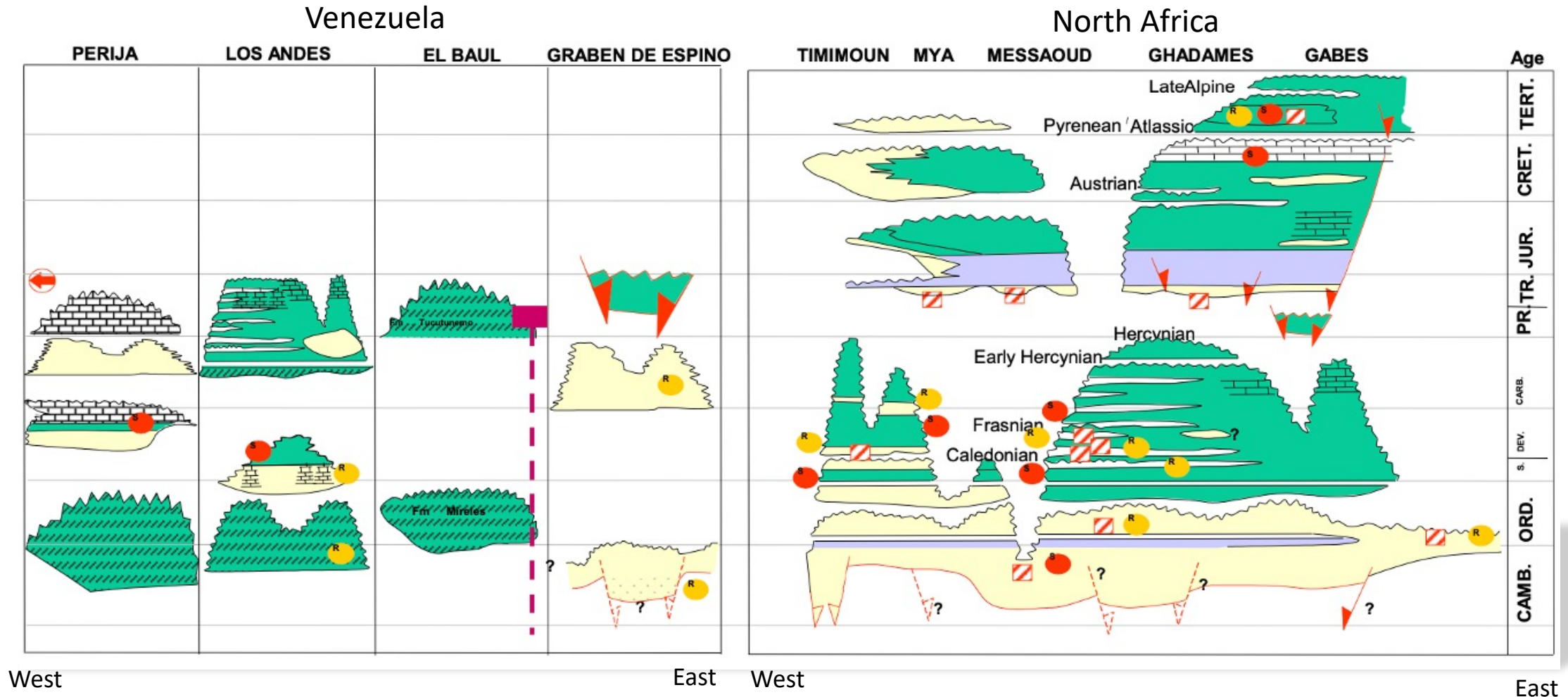
> 90% world oil and gas



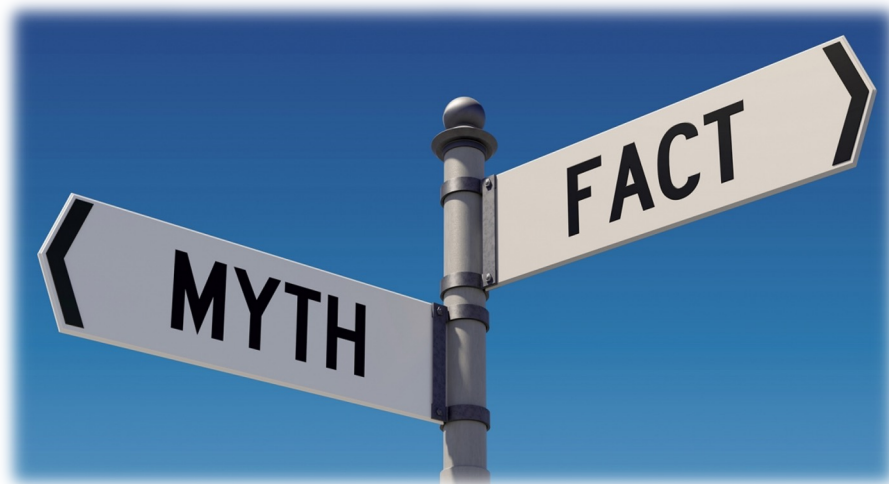
Pz Analogous

- **Reservoirs:** They produce oil but mainly gas and related with matrix dissolution and dolomitization more than primary porosity
- **Source and Charge :** Mainly shales with kerogen type I and II:
 - Anadarko, Permian, Michigan (Silurian)
 - Arkoma Indiana-Ohio Basins (PLP)
 - McArthur Basin (Australia, 1400-1600 Ma).
 - Lena-Tunguska (Siberia, Upper Proterozoic - Pz)
 - Oman (Ediacaran - Cambrian).
 - Ordos, Tarim, Sichuan and Dohai Bay Basin (China, Cryogenian limestones).
 - South Africa (Archaic).
 - Toudeni Basin (Gas, Northern Mali, Precambrian)
- **Seals** mainly evaporites and shales
- **Traps** related with paleo-highs, slope areas and platform margins

Pz Analogous



Project Contribution



Myths about the Colombian Palaeozoic

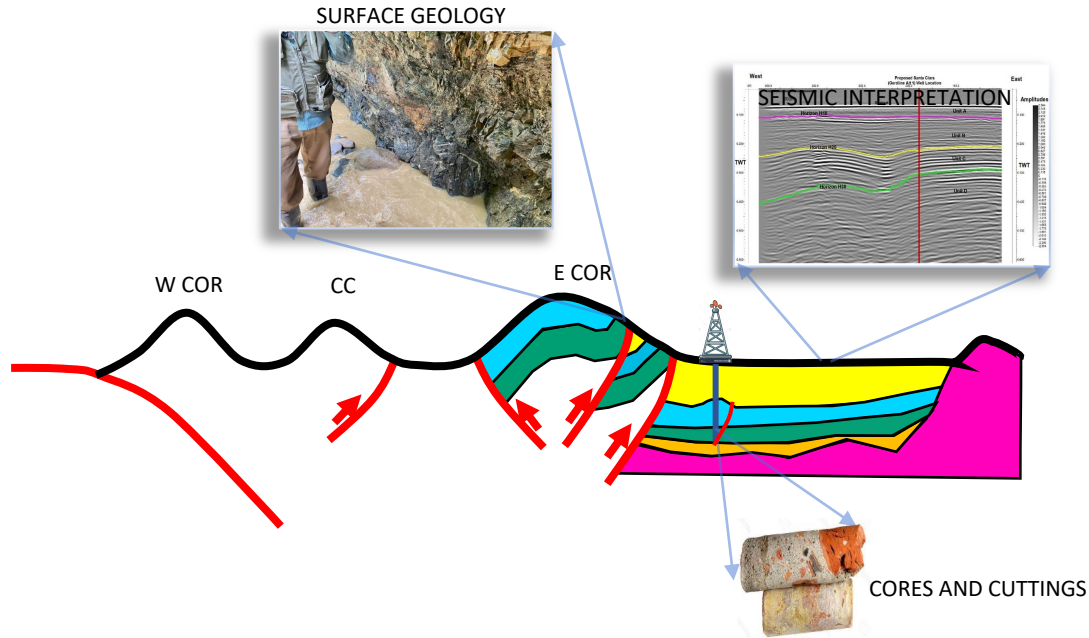
- Metamorphism (Regional, Contact and Dynamic)
- TOC (Absent or very low)
- Organic matter post-mature
- Tight rocks
- High Tectonic deformation and fracturing
- Not enough thickness

The Palaeozoic in Colombia is a frontier - The aim of this Project is to find out whether or not there is some potential in these sequences.

In the case of finding a good source rocks, Pz can have interest for Conventionals and Unconventionals.

To propose areas that can have good conditions for continuing acquiring more Information to prove the potential in the Palaeozoic

Project Scope:



LAB ANALYSIS:

- Petrography*
- Petrophysics*
- Geochem*
- Palaeontology*
- DRX*



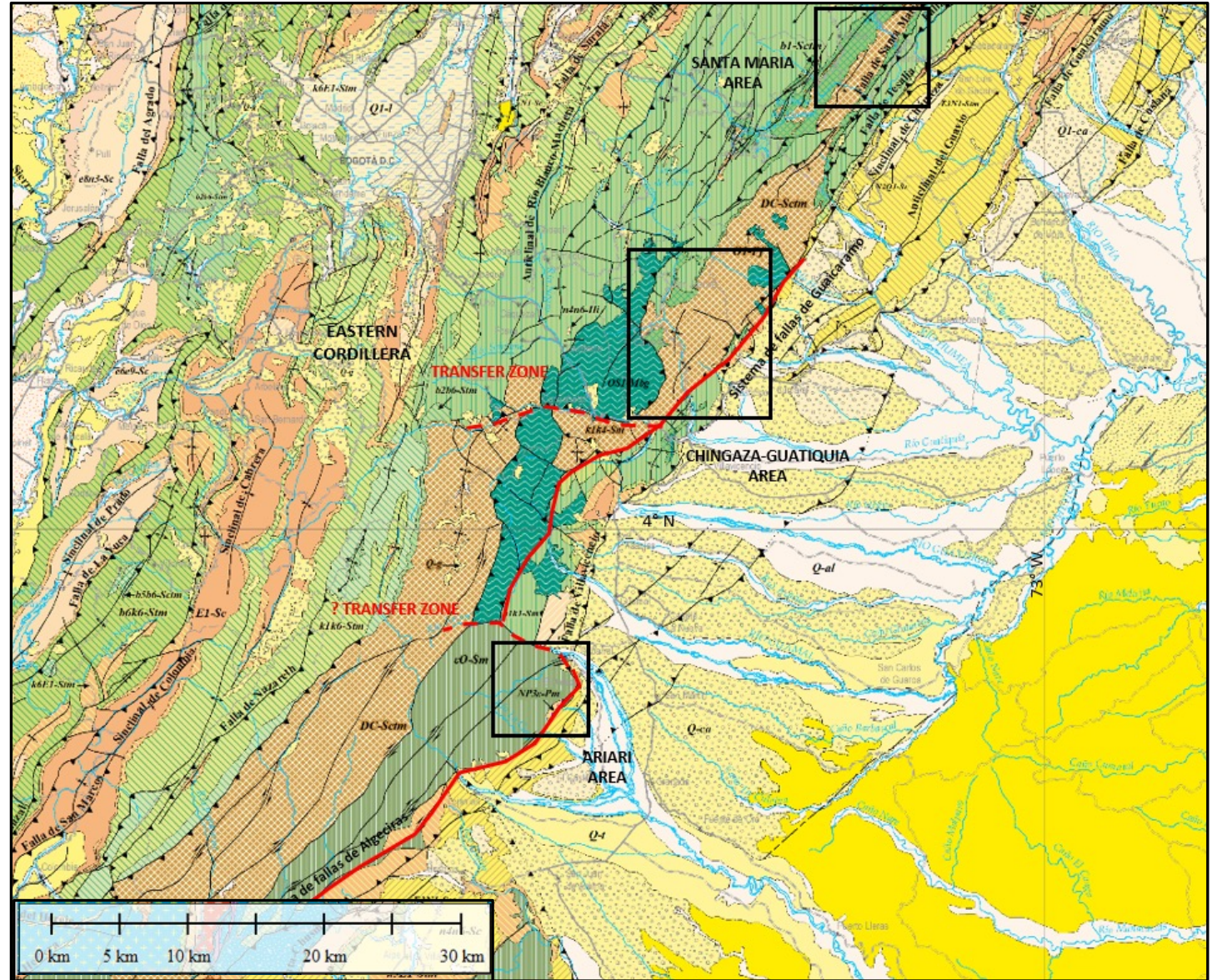
- Stratigraphy
- Structural
- Petrophysics
- Geochemistry

Location Of The Studied Areas

For this study we selected three areas on the Eastern Cordillera and foothills of Colombia, Rio Bata (Boyacá), Guatiquia y Ariari (Meta).

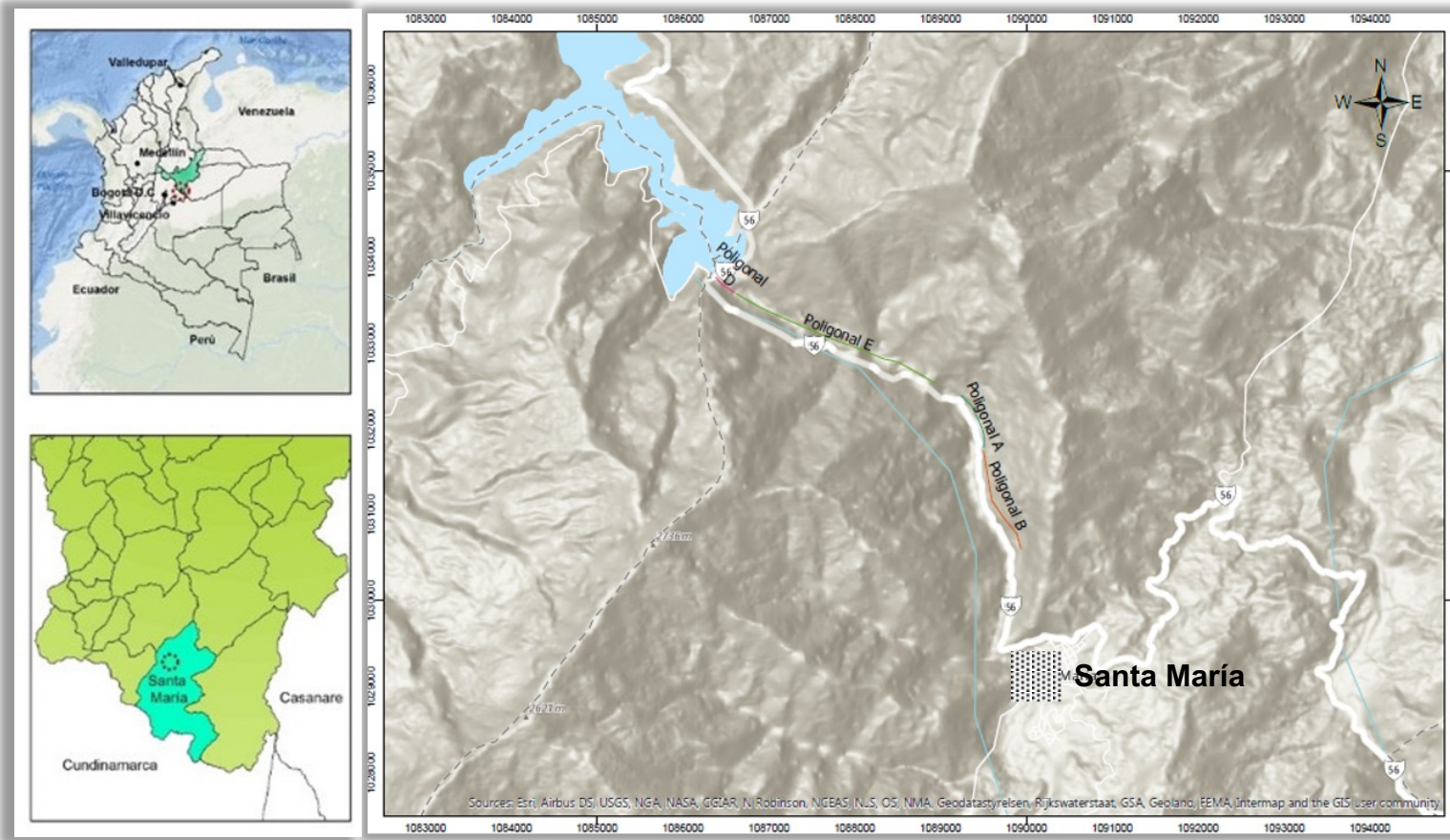
The foothills of the Cordillera are dominated by thrusts towards the foreland.

Paleozoic units are exposed in the hanging wall of main thrust that are affected by transfer zones.



Bata Area

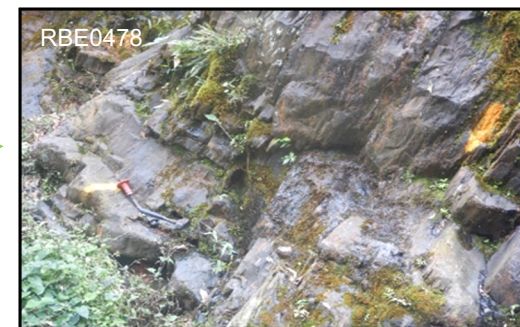
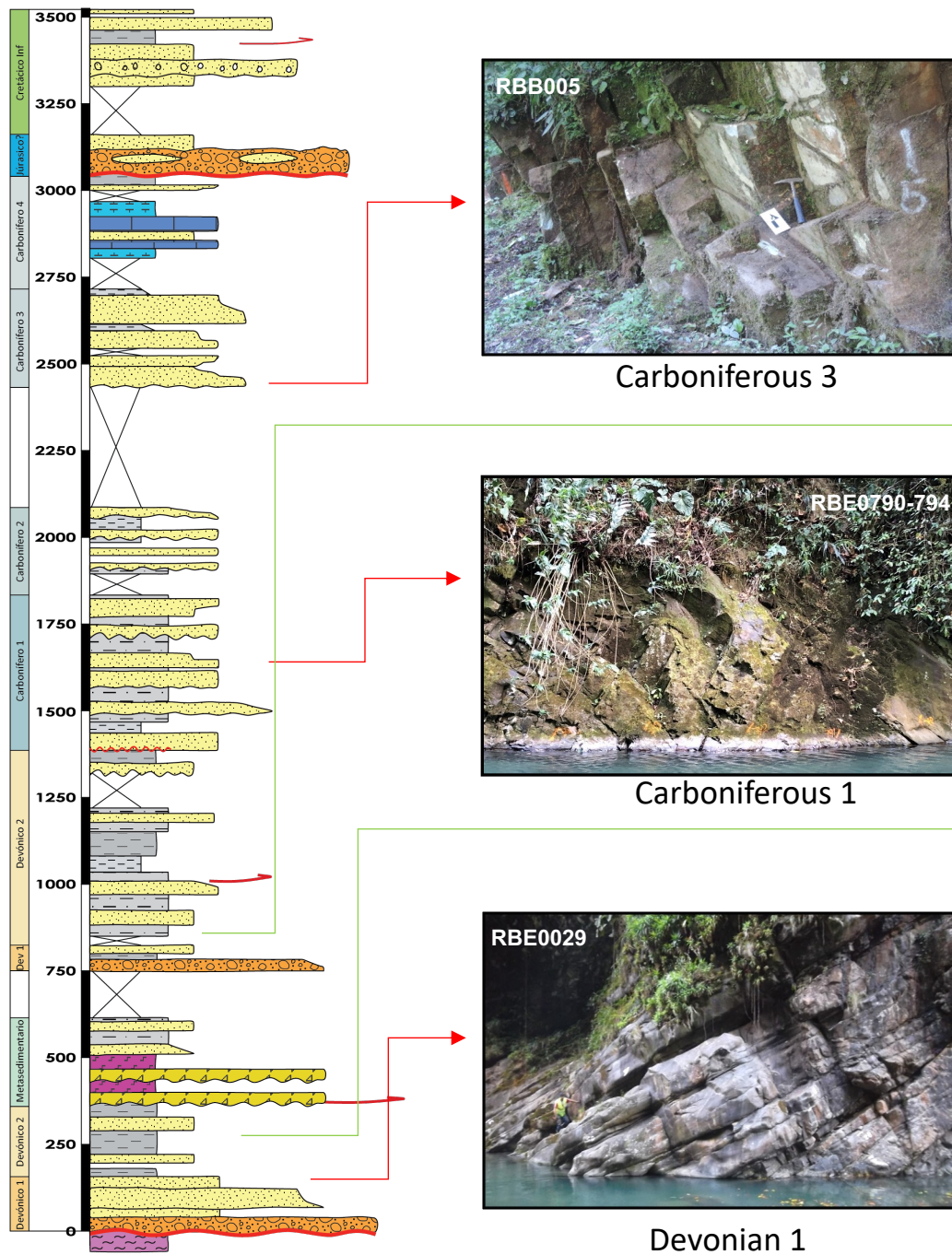
The stratigraphic section “Río Batá” is located approximately 7 Km to the NW of Santa María village, in the south of the Boyaca Department.



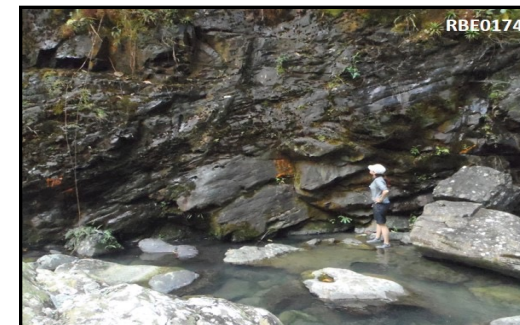
Lithological description
Samples

: 2382,5 m
: 1267 (petrography, geochemical analysis, petrophysics, geochronology)

Stratigraphic Column Batá Area (aprox 2400 m)

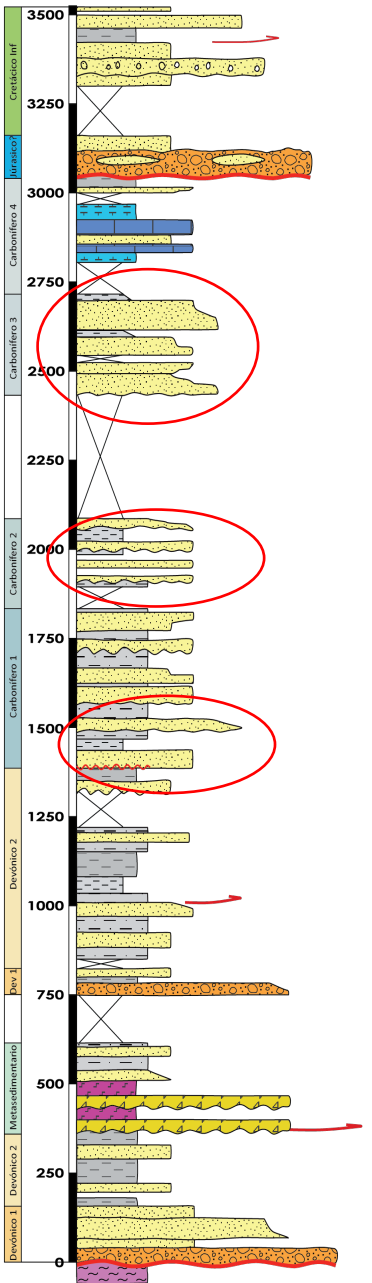


Devonian 2

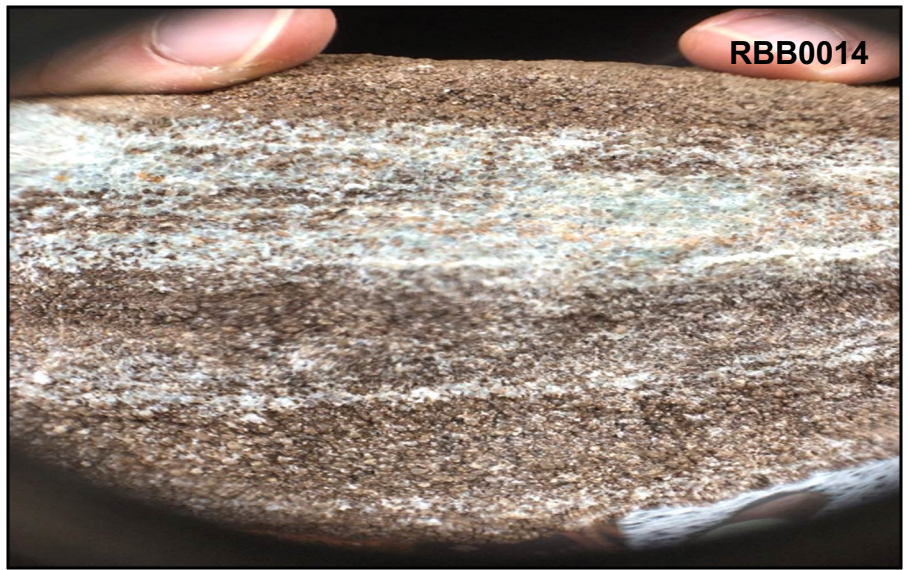


Devonian 2

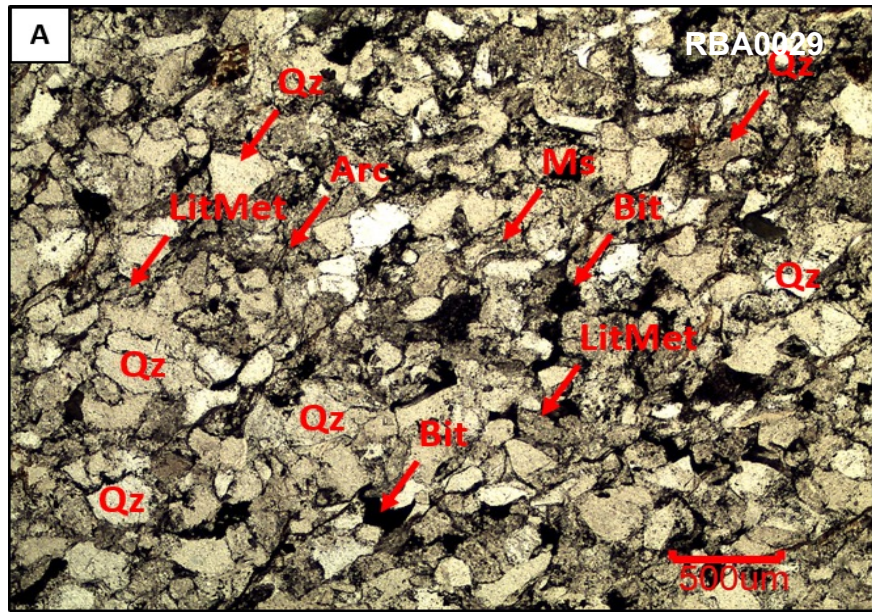
Devonian 1



Middle layers of sandstone with oil stains (Carboniferous 3)



Sandstone of quartz with oil stains (Carboniferous 3)

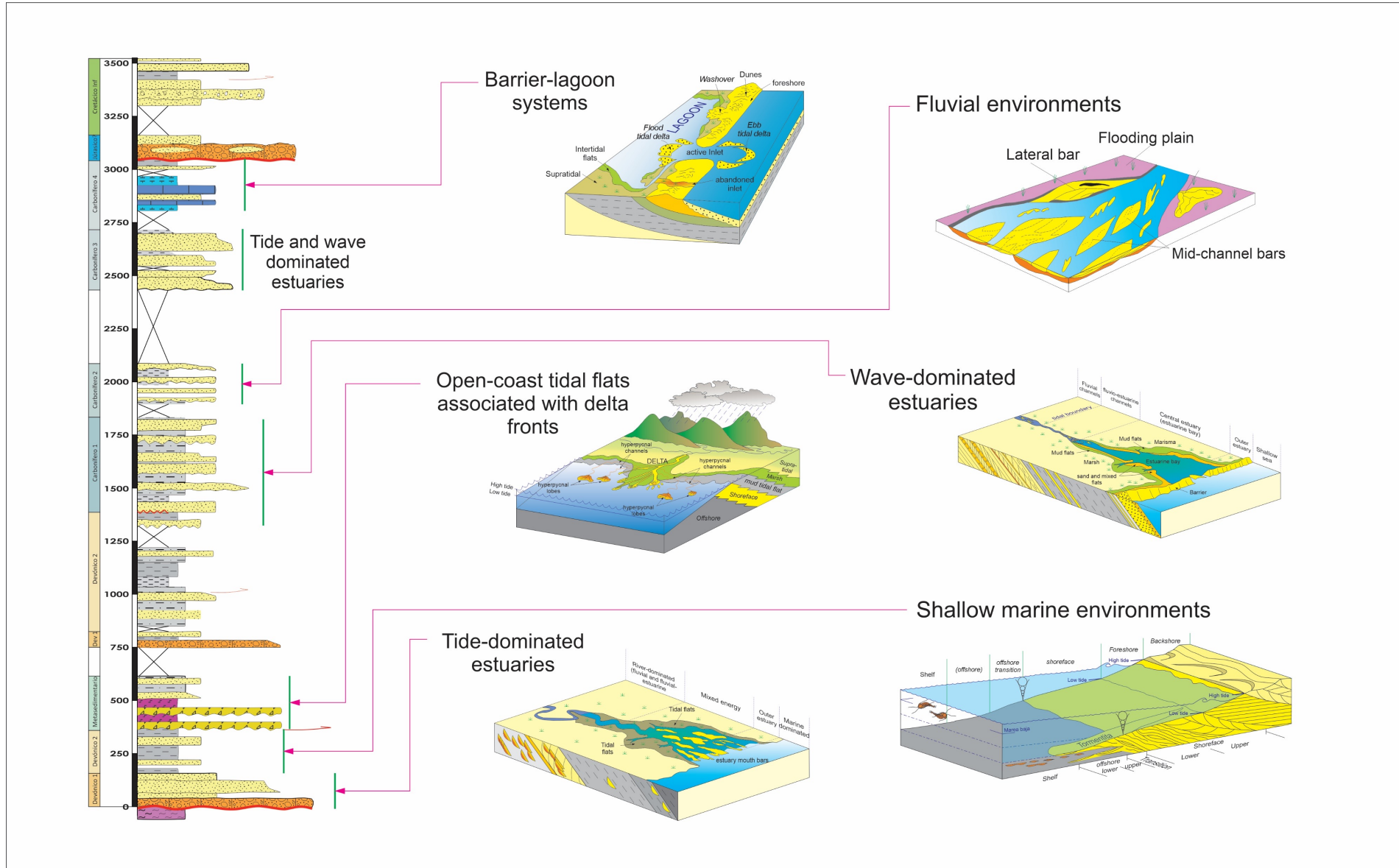


Sandstone with bitumen filling pore spaces (Carboniferous 2).

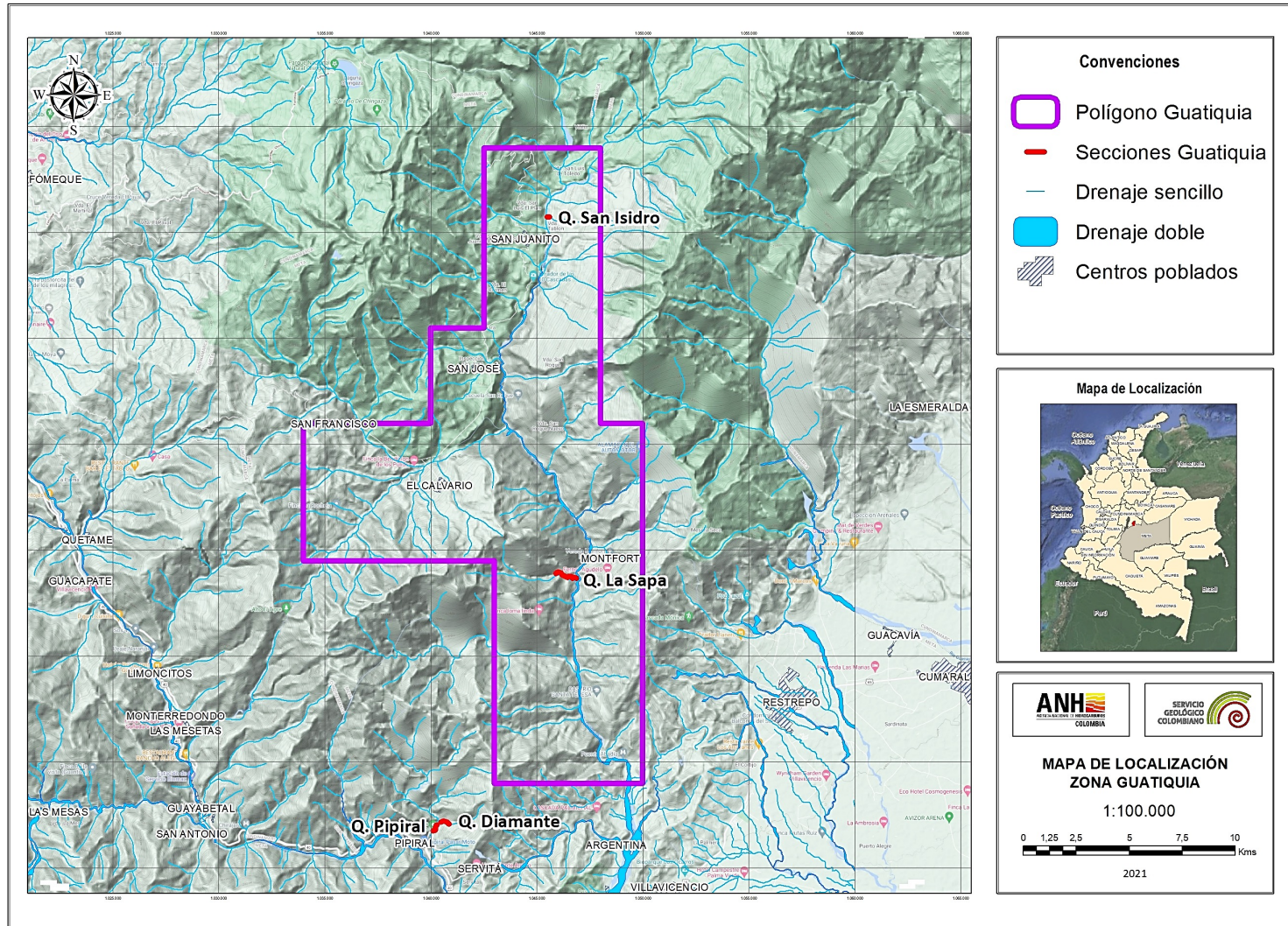


Fine sandstone with oil stains (Carboniferous 1).

Sedimentary Environment (Bata Section)



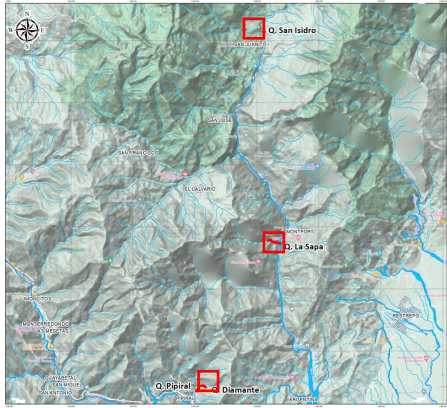
Guatiquía Area



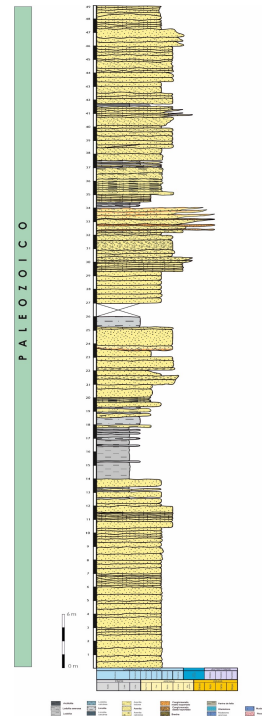
The Guatiquia area comprises a 260 km² polygon in which 4 stratigraphic sections were measured. This área is located in the Department of Meta, in the municipalities of San Juanito, El Calvario y Villavicencio.

- Quebrada San Isidro
- Quebrada La Sapa
- Quebrada El Diamante
- Quebrada Pipiral

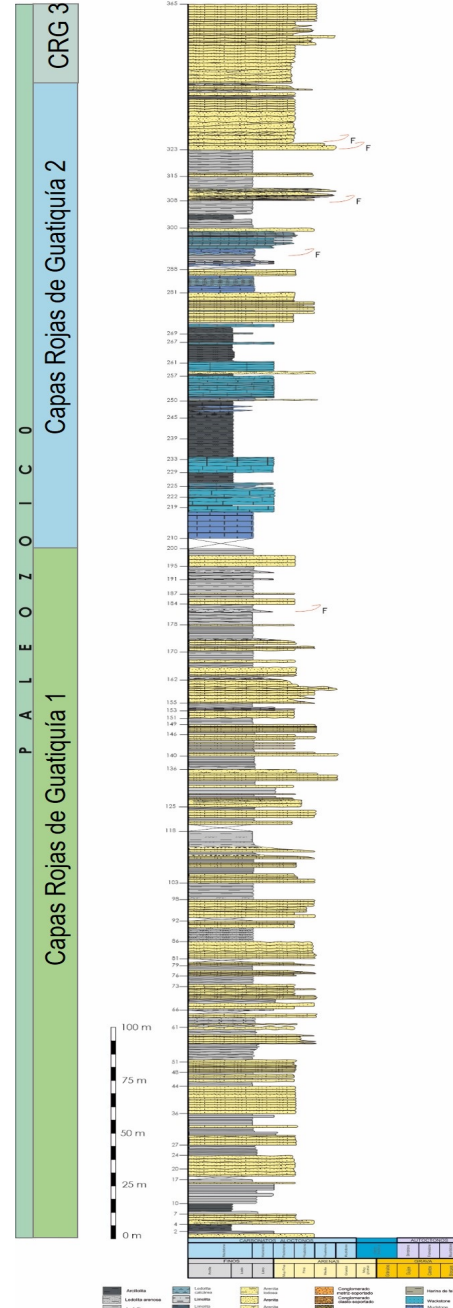
Total thickness without cover: 1090 m
Samples: 331



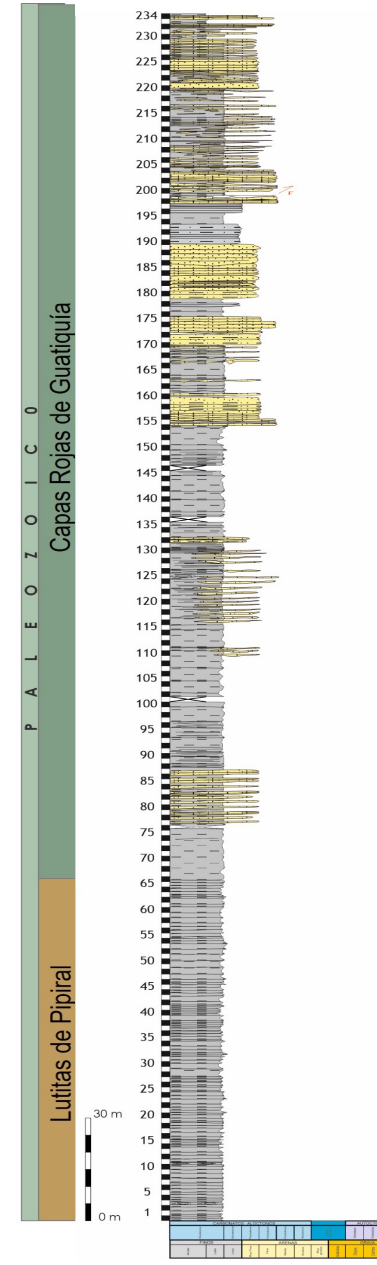
Qb San Isidro
(70 m)



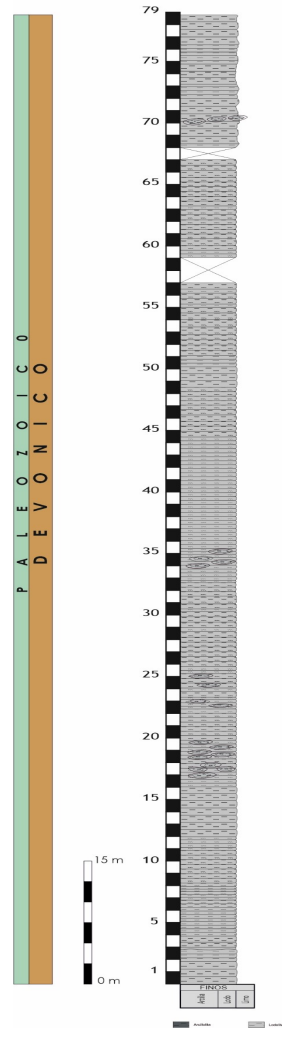
Qb La Sapa
(550 m)



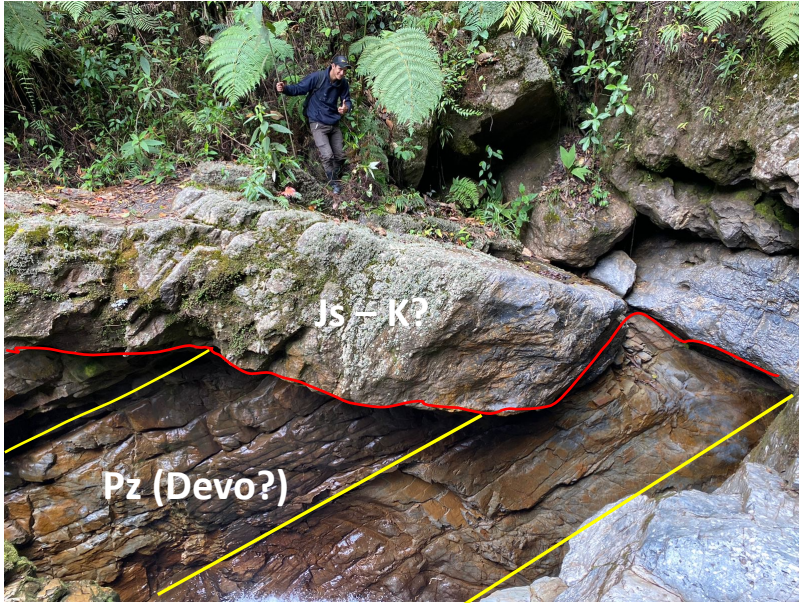
Qb El Diamante
(352 m)



Qb Pipiral
(120 m)



Guatiquía Area – Stratigraphic Columns



Angular unconformity Pz – Js, Qb San Isidro



Crinoid in beds of Capas Rojas del Guatiquía; Qb La Sapa



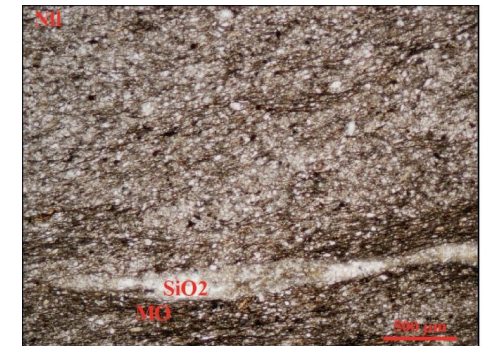
Pice of coral in beds of Capas Rojas del Guatiquía; Qb La Sapa



Mudstone and claystone, Lutitas de Pipiral Fm, Qb Pipiral



Mudstone and claystone, Lutitas de Pipiral Fm Qb Diamante

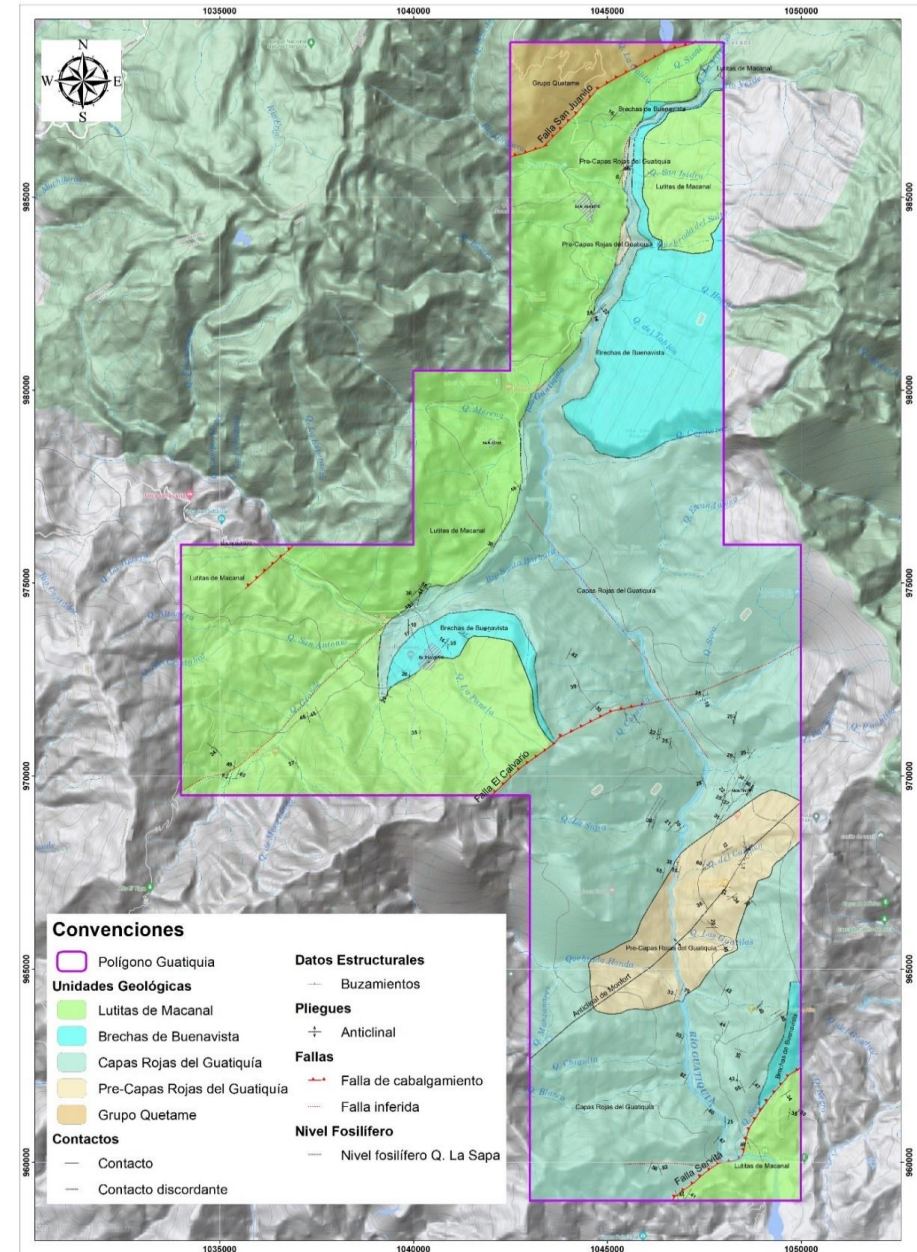
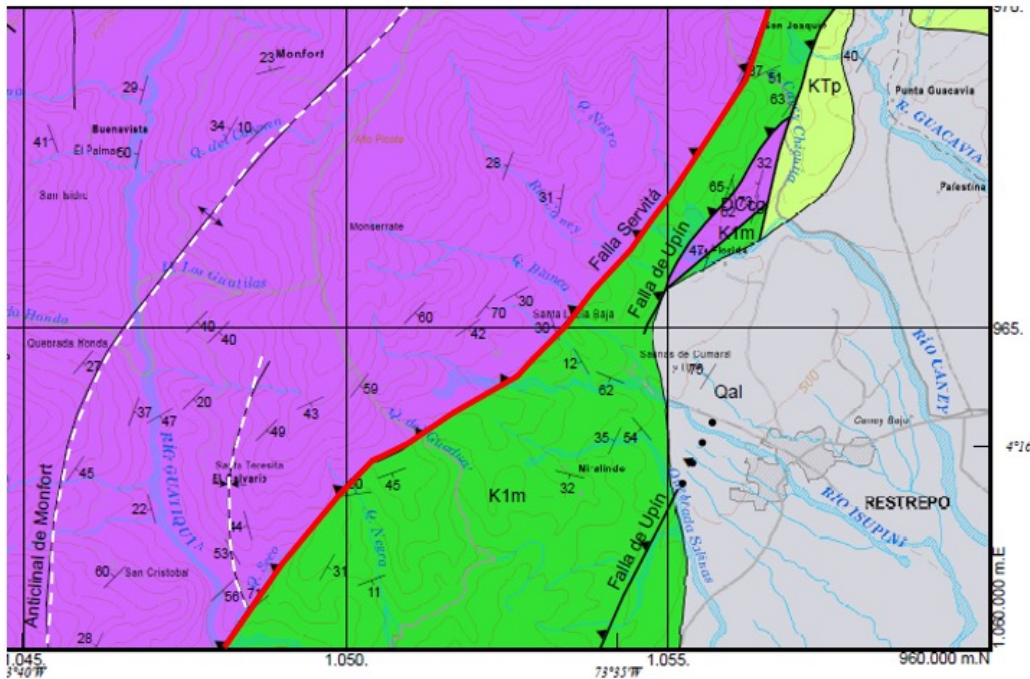


Claystone with organic matter

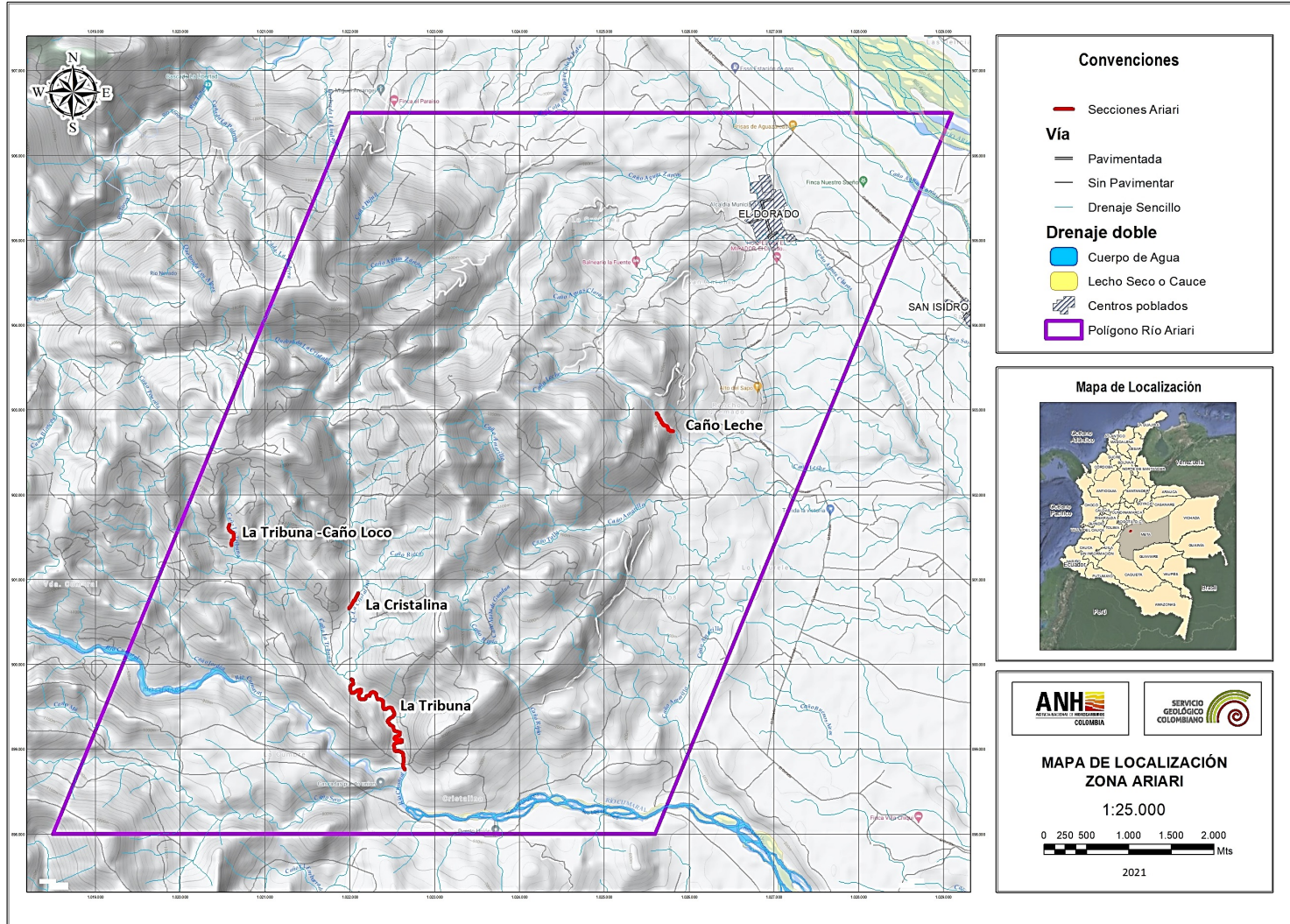
Guatiquia Area - Geological Mapping

In this sector two units are differentiated within the Palaeozoic rocks. One called Pre-Capas Rojas de Guatiquía (Devonian?) and other one Capas Rojas de Guatiquía (Carboniferous)

The main structures correspond to Monforth Anticline, The Calvario fault and San Juanito Fault.



Ariari Area

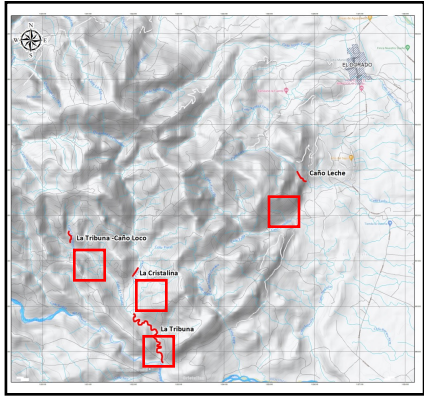


The Ariari area is 60 km², in which 4 stratigraphic columns were measured. This area is located in the Department of Meta, near to the El Dorado village.

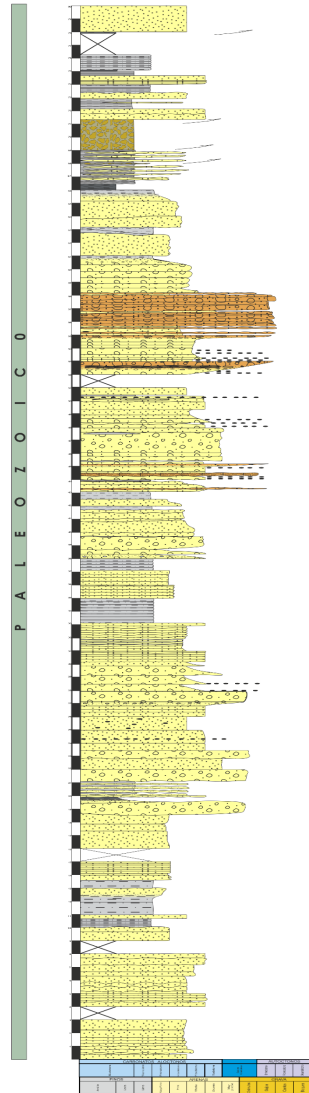
- Column Qb La Tribuna
- Column Qb La Cristalina
- Column Qb La Tribuna – Caño Loco
- Column Qb Caño Loco

Total stratigraphic thickness : 952 m
Samples: 214

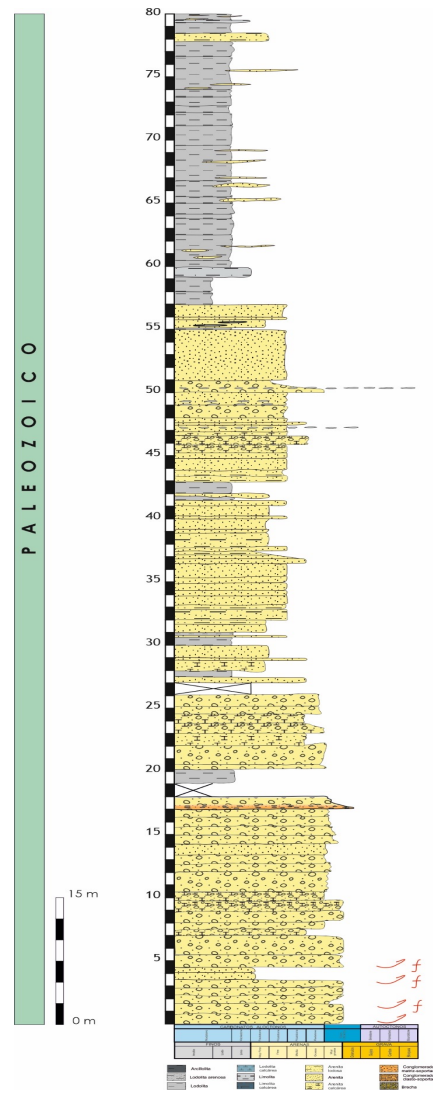
Ariari Area – Stratigraphic Columns



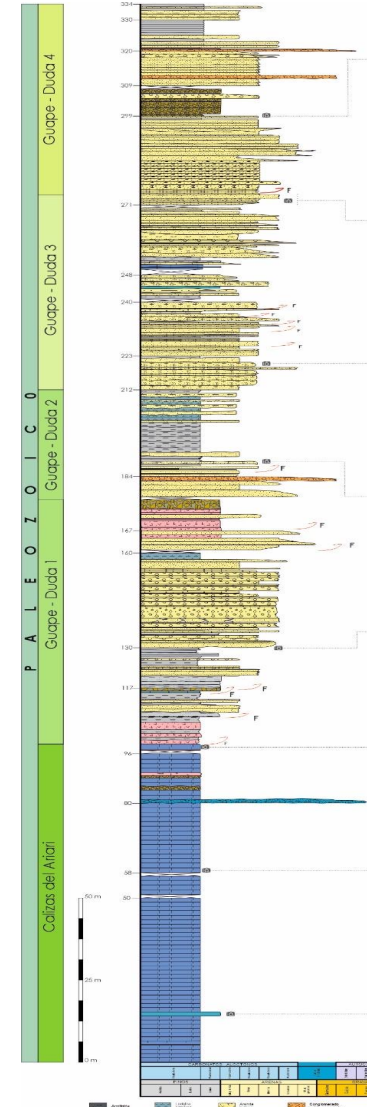
Qb La Tribuna – Caño Loco
(120 m)



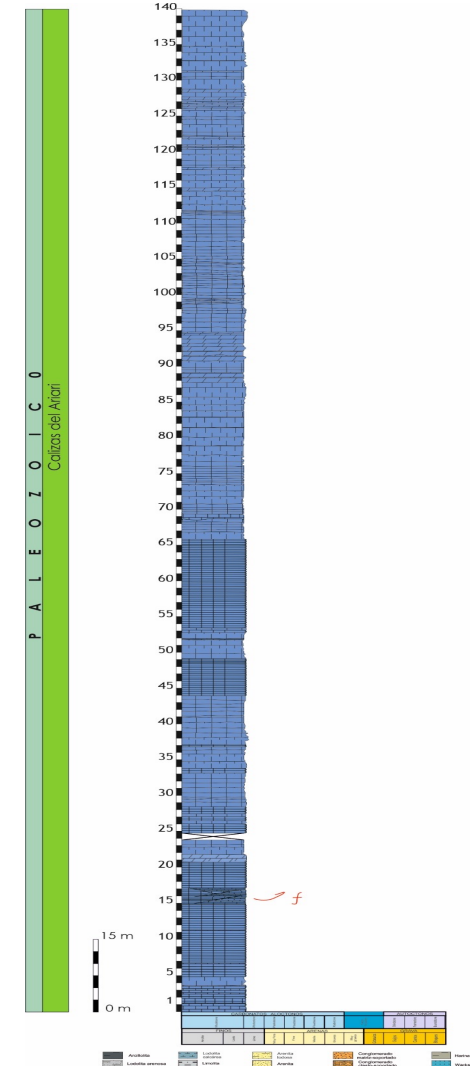
Qb La Cristalina
(120 m)

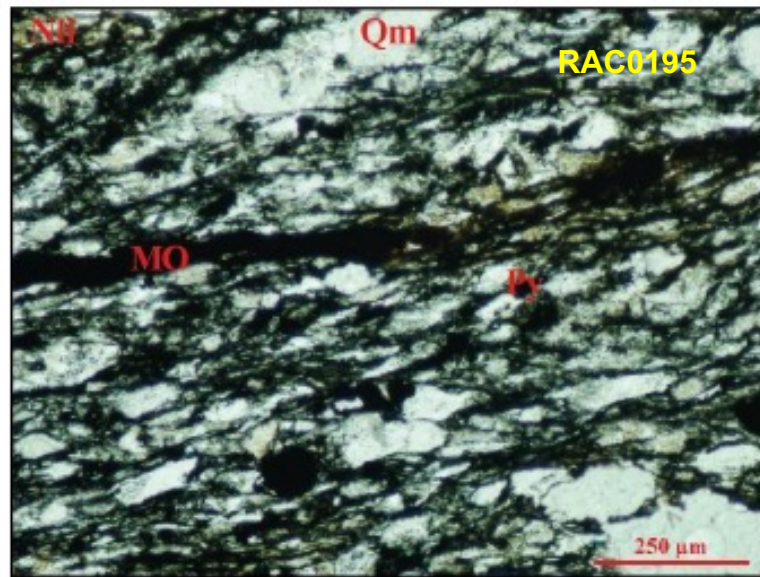
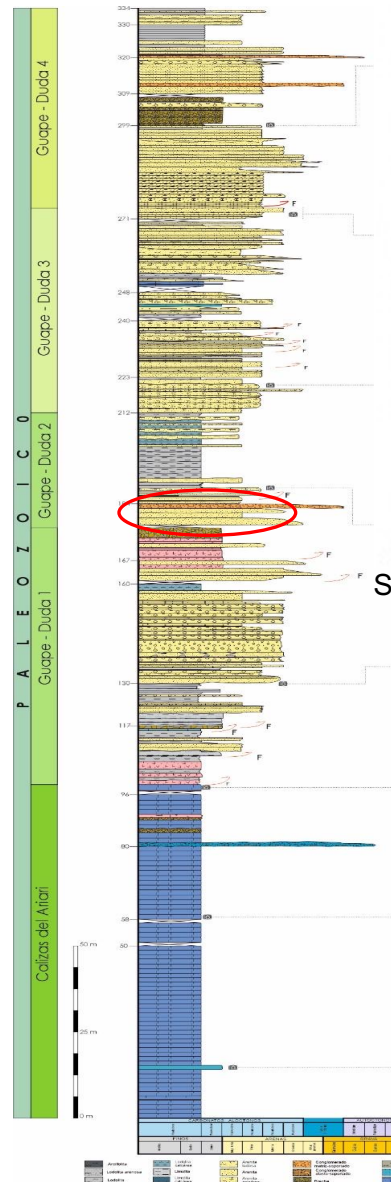


Qb La Tribuna
(502 m)

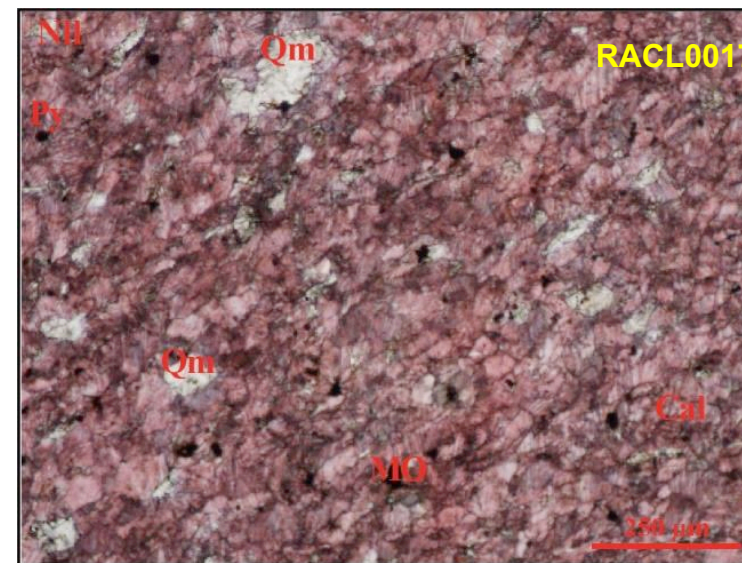


Qb La Caño Leche
(210 m)

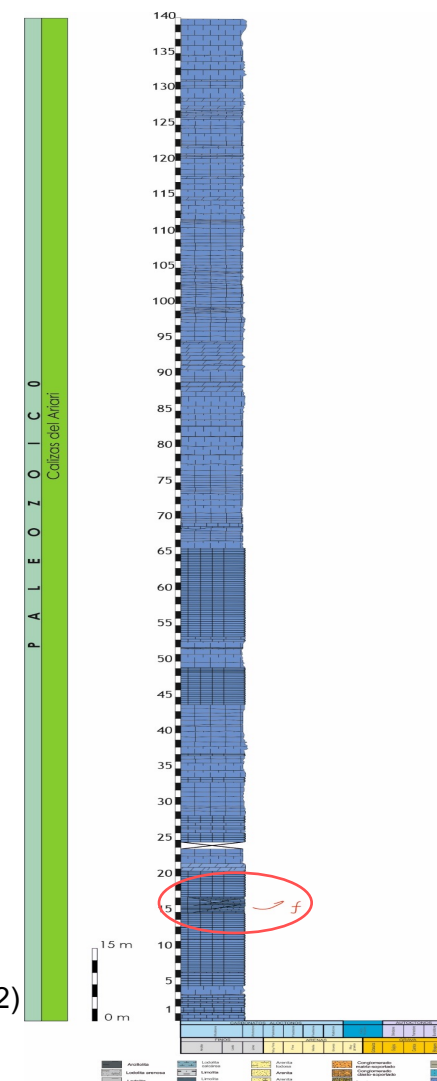




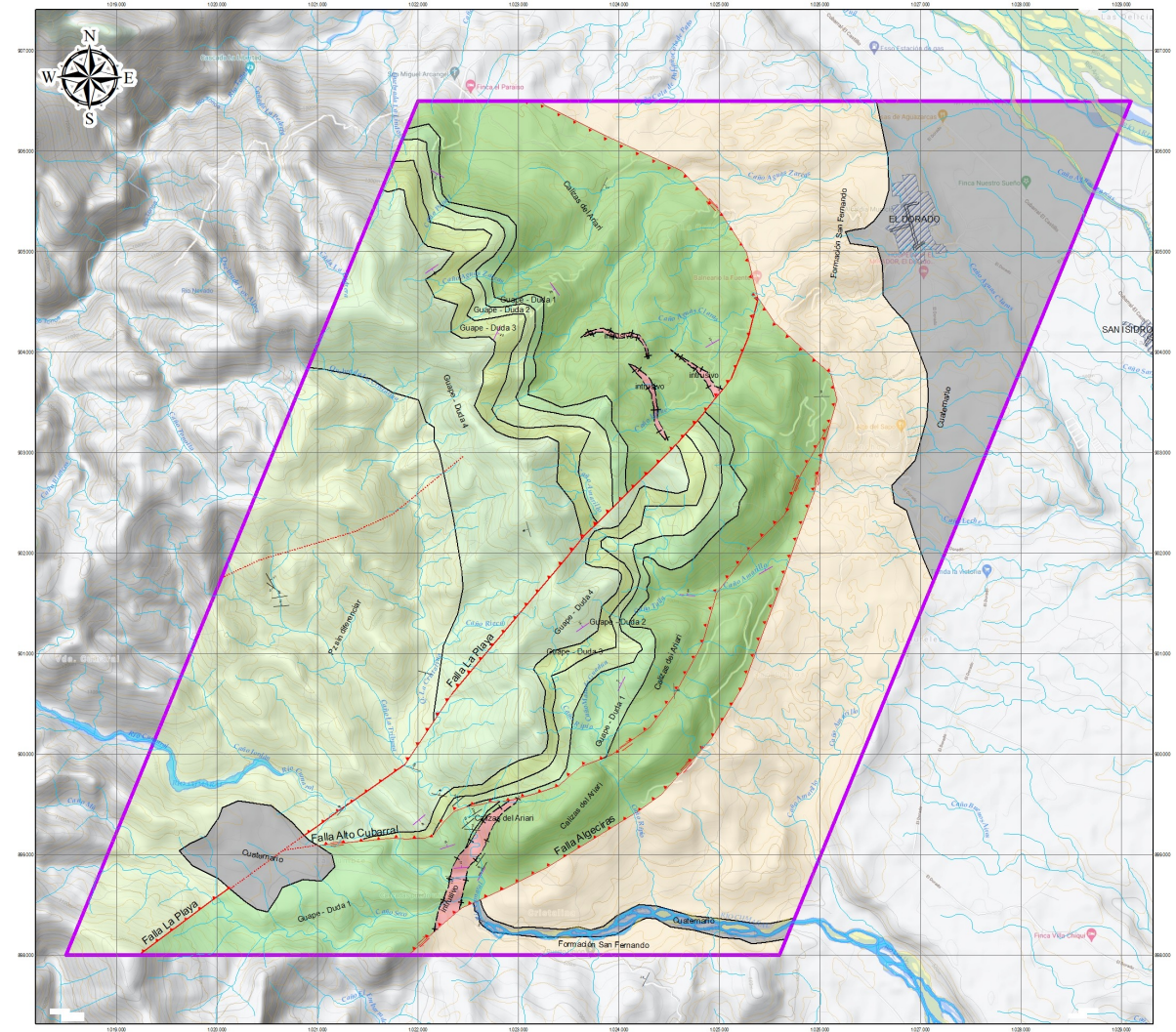
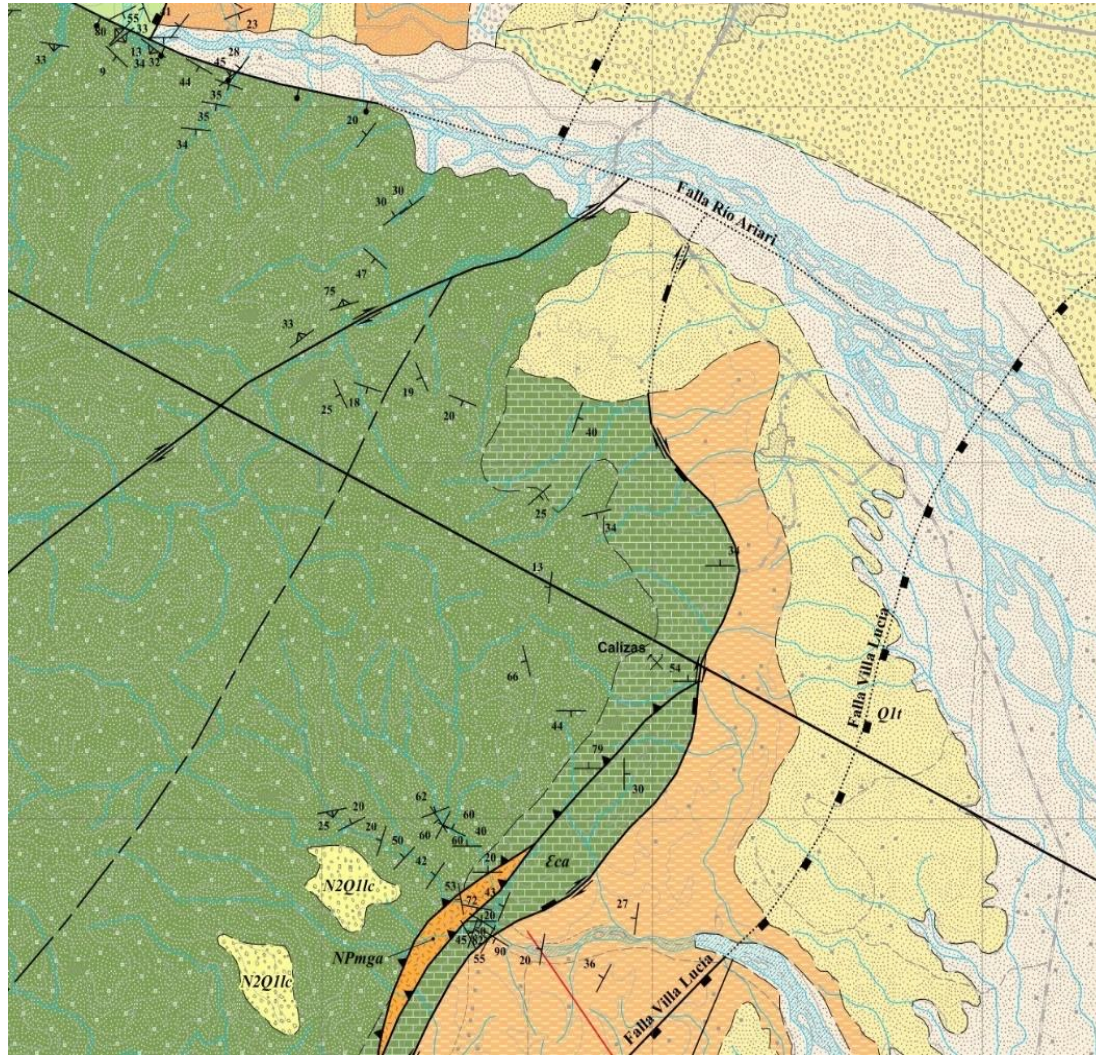
Sandstone with organic matter., Qb La Tribuna (Guape-Duda 2)



Sandstone with organic matter., Qb La Tribuna (Guape-Duda 2)



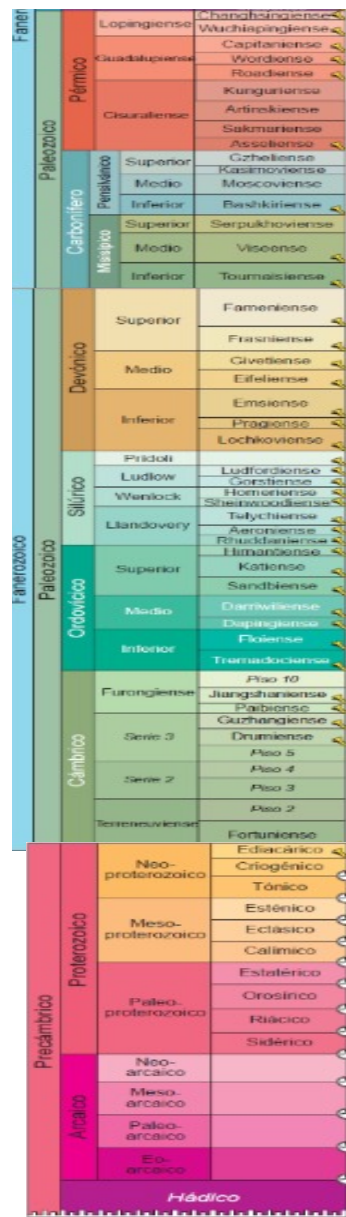
Ariari Area – Geological Mapping



In the geological mapping it was possible to divide the Palaeozoic rocks into 5 lithological different units, four igneous bodies, and three fault (Algeciras, Alto Cubarral y la Playa)

G&G Interpretation: What has been done?

P
A
L
E
O
Z
O
I
C

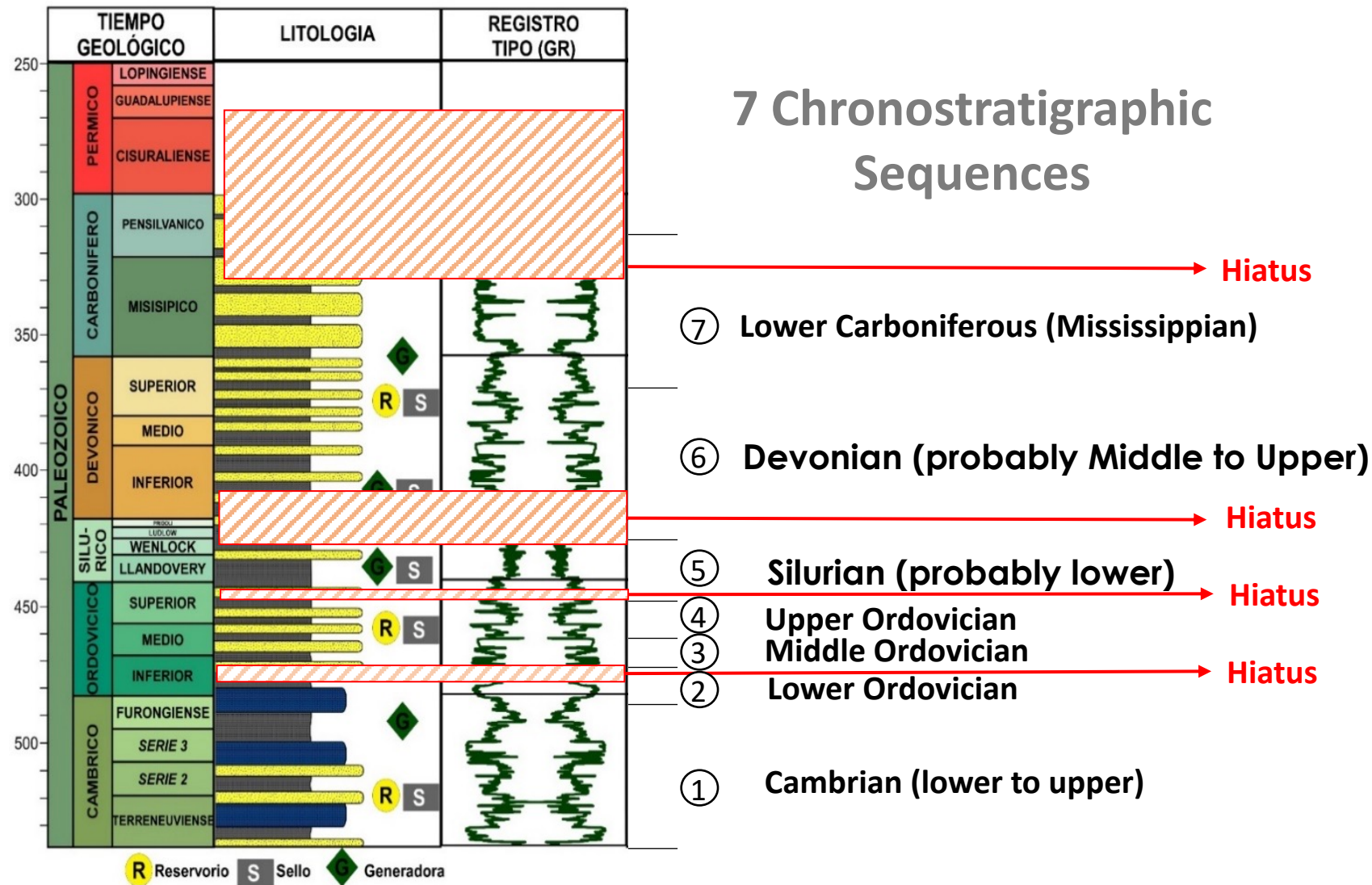


- ✓ Regional Petrotechnical project
- ✓ 15000 km of reprocessed seismic data interpreted
- ✓ 406 wells reviewed
- ✓ 80 wells studied and analyzed
- ✓ Biostratigraphic revision and validation
- ✓ Distribution of updated chronostratigraphic sequences
- ✓ 8 Regional seismic sections
- ✓ 9 Stratigraphic correlations
- ✓ Identification of structural domains
- ✓ Maps in time and depth

Generalized Stratigraphic Column

Criteria:

Biostratigraphic (chronostratigraphic), Seismic and Stratigraphic (core analysis).

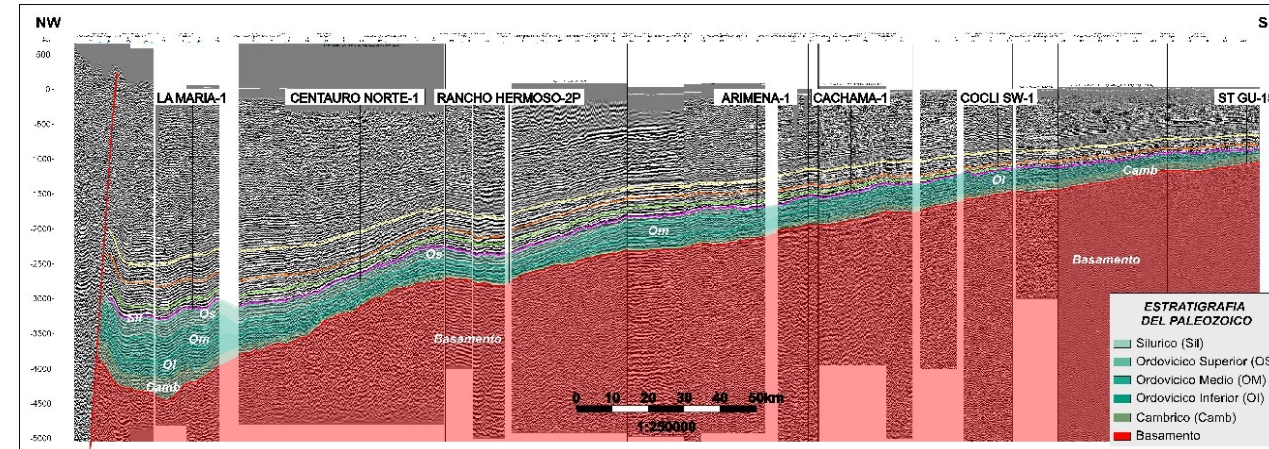
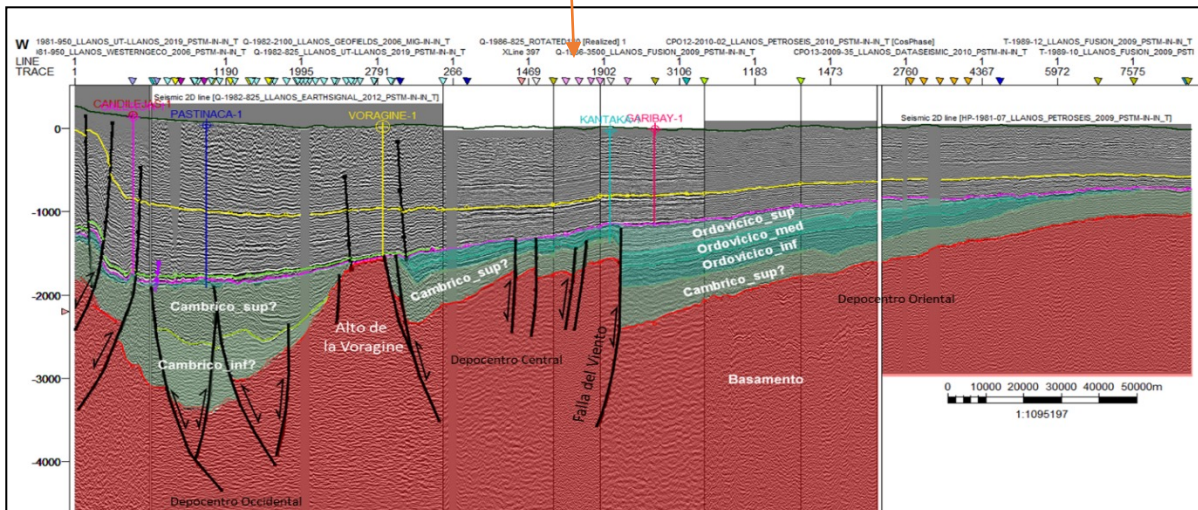
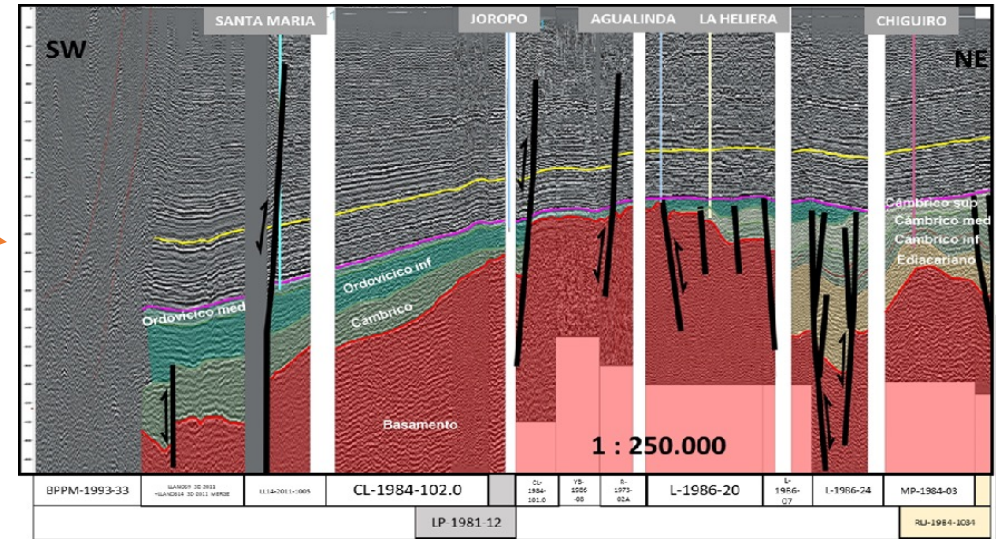
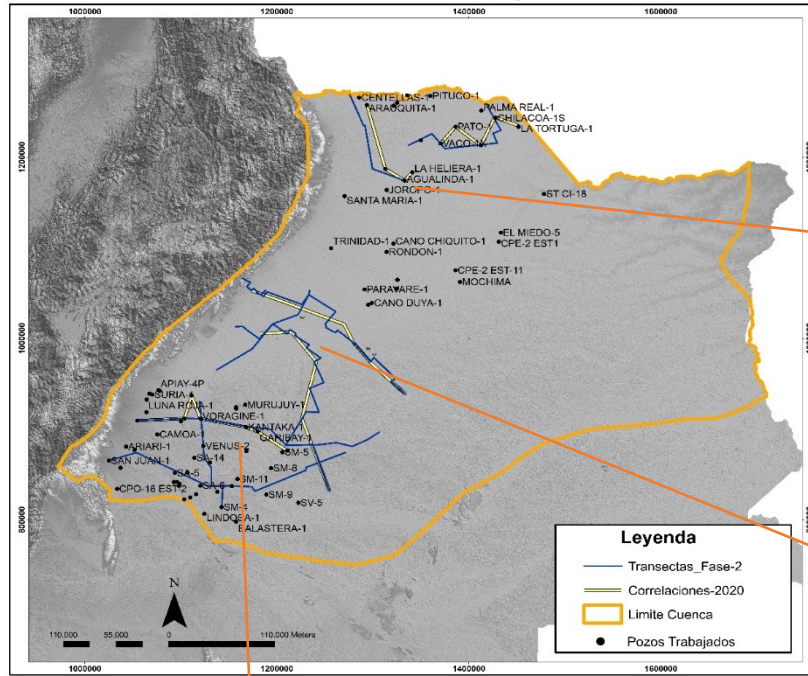


Palynological Zones

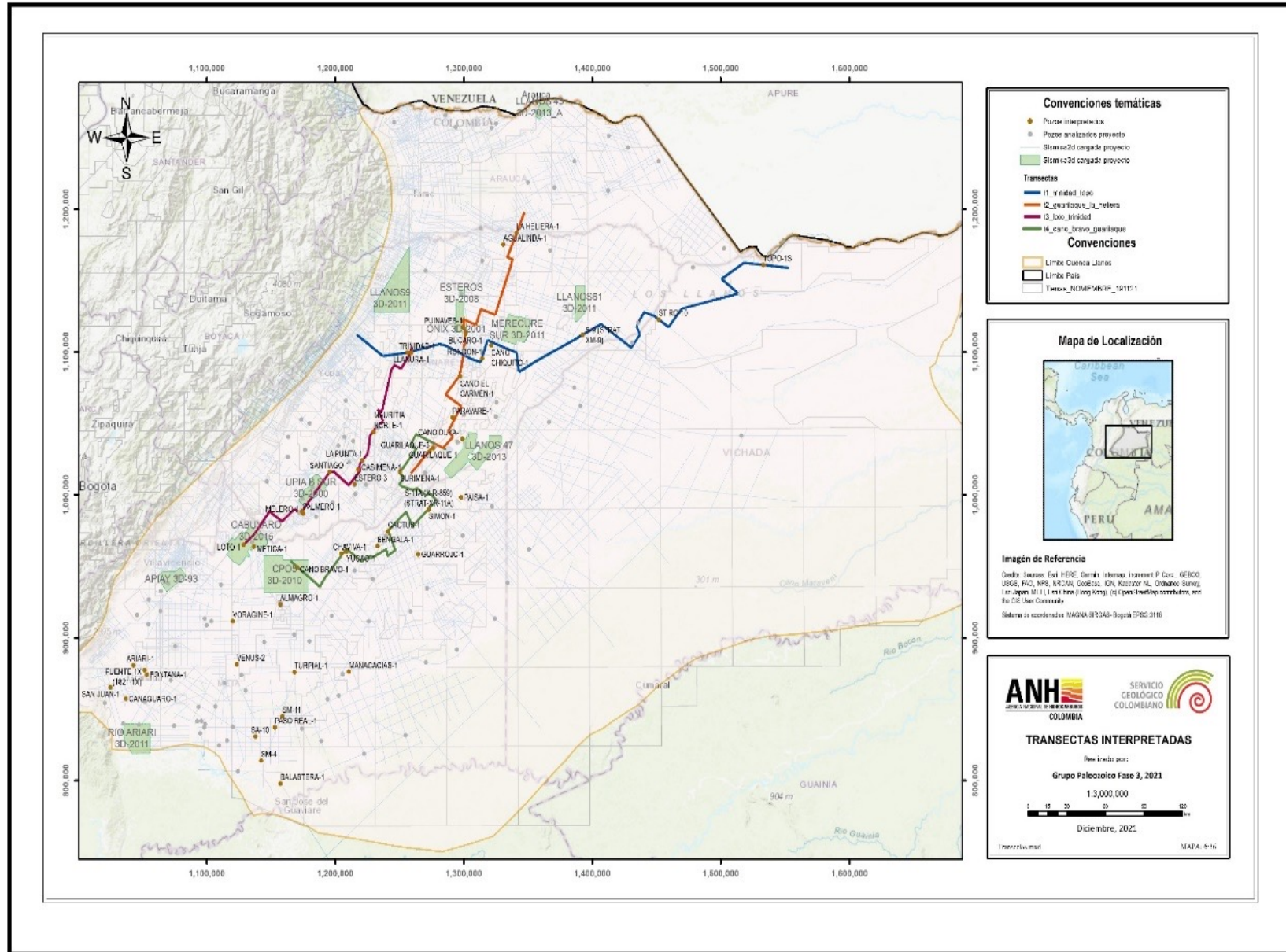
-Preliminar-

Periodo	Subperiodo	Zona	Edad (Ma)	Localidad	
Carbonífero	Pensilvanico	Superior	298.9 ± 0.15		
			Gzhelense	303.7 ± 0.1	
			Kasimoviense	307.0 ± 0.1	
		Medio	315.2 ± 0.2		
		Inferior	323.2 ± 0.4		
	Missipico	Superior	330.9 ± 0.2		
			Serpukhoviense	346.7 ± 0.4	CO-1 SM-4
			Viseense	358.9 ± 0.4	
	Devónico	Superior	Fameniense	372.2 ± 1.6	DO-3 SM-4
			Frasniense	382.7 ± 1.6	
Givetense			387.7 ± 0.8		
Eifelense			393.3 ± 1.2		
Medio		Emsiense	407.6 ± 2.6		
		Pragiense	410.8 ± 2.8		
		Lochkoviense	419.2 ± 3.2		
Inferior		Pridoli	423.0 ± 2.3	SI-3 San Juan-1	
		Ludlow	425.6 ± 0.9		
Silúrico		Wenlock	Gorstense	427.4 ± 0.5	
	Homeriense		430.5 ± 0.7		
		Shelwoodense	433.4 ± 0.8		
	Llandovery	Telychiense	438.5 ± 1.1	SI-1 Pazo Real-1	
		Aeroniense	440.8 ± 1.2		
Ordovícico	Superior	Rhuddaniense	443.8 ± 1.5	OR-5 Loto-1	
		Hirnantense	446.2 ± 1.4	OR-4 Rancho Heroso 2P	
		Katiense	453.0 ± 0.7	OR-3 Rancho Heroso 2P	
	Medio	Sandbiense	458.4 ± 0.9	OR-2 Rancho Heroso 2P	
		Dartwiliense	467.3 ± 1.1	OR-1 Rancho Heroso 2P	
		Dapingiense	470.0 ± 1.4		
	Inferior	Floense	477.7 ± 1.4		
		Tremadociense	485.4 ± 1.9	CB-3 Chiguiro-1	
	Cámbrico	Furongiense	Piso 10	~ 489.5	
			Jiangshaniense	~ 494	
Paibiense			~ 497		
Miacolingiense		Guzhangense	~ 500.5		
		Drumiense	~ 504.5	CB-2 Chiguiro-1	
		Wuliense	~ 509		
Serie 2		Piso 4	~ 514		
		Piso 3	~ 521		
Terransuviense		Piso 2	~ 529		
		Fortuniense	541.0 ± 1.0		
Ediacárico		~ 635	E-3 Chiguiro-1		

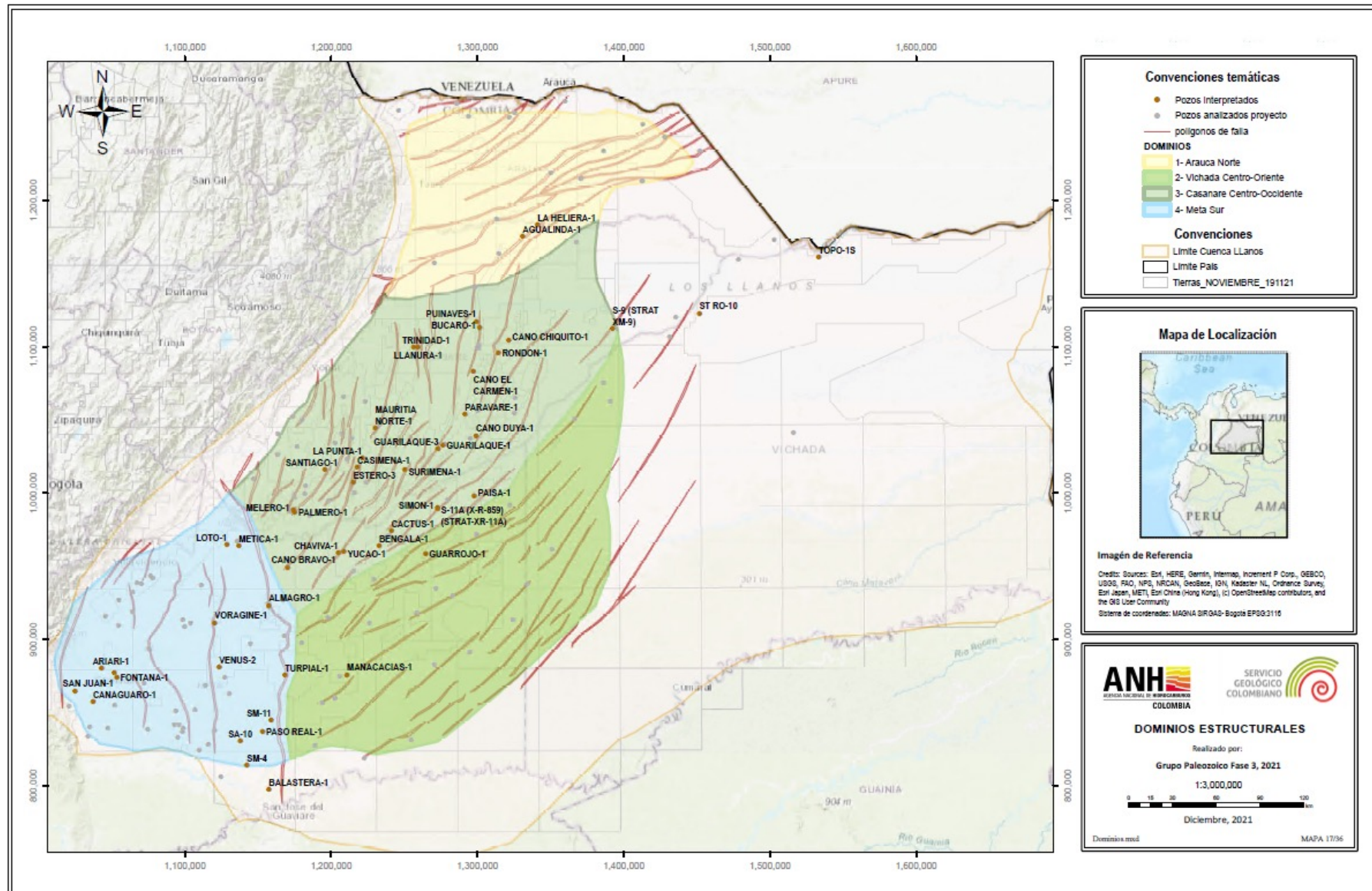
Seismic sections: phases 1 & 2



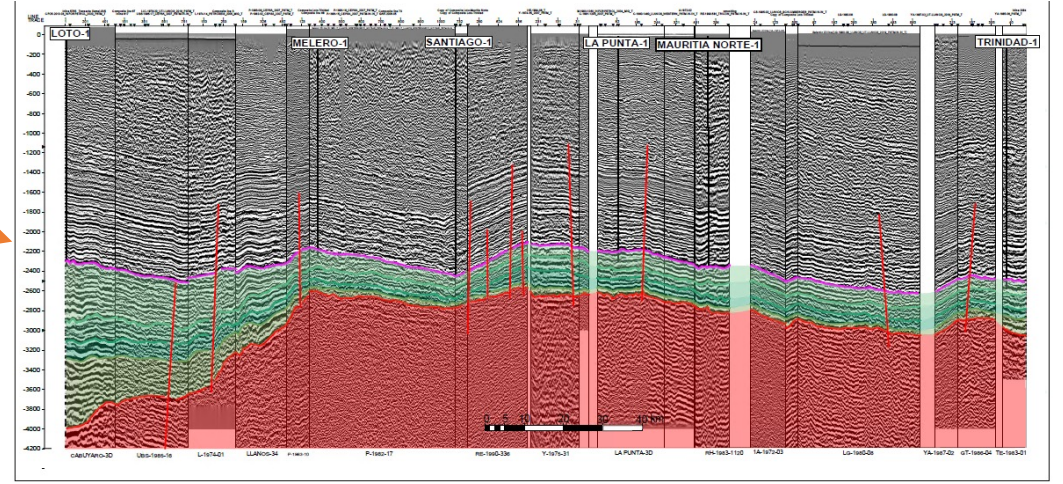
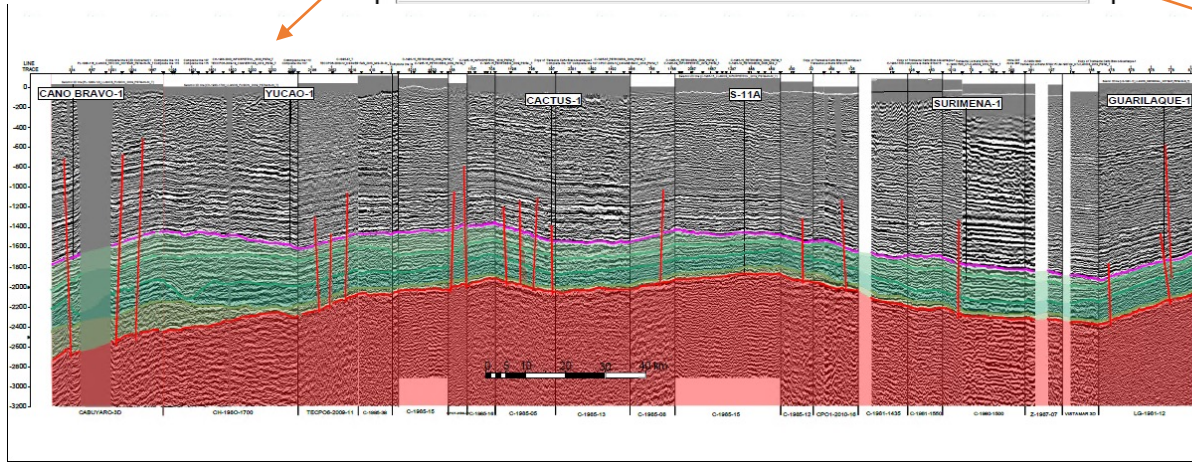
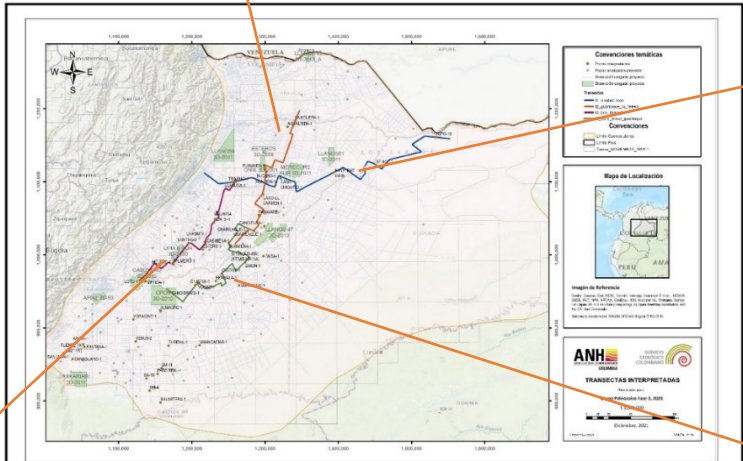
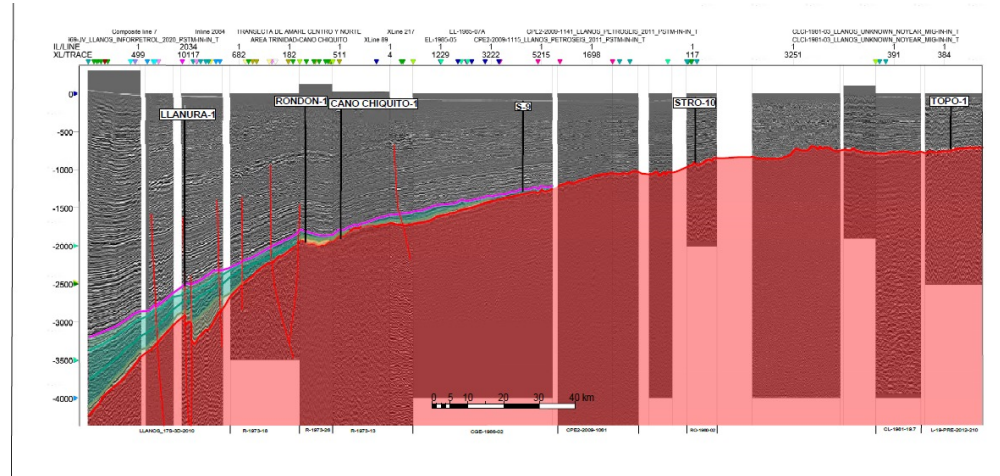
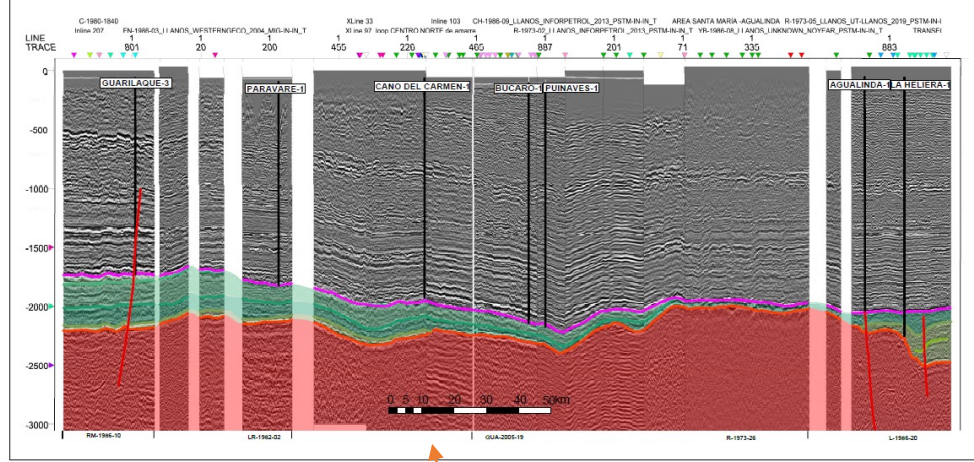
Geophysical Interpretation Phase 3



Structural Domains

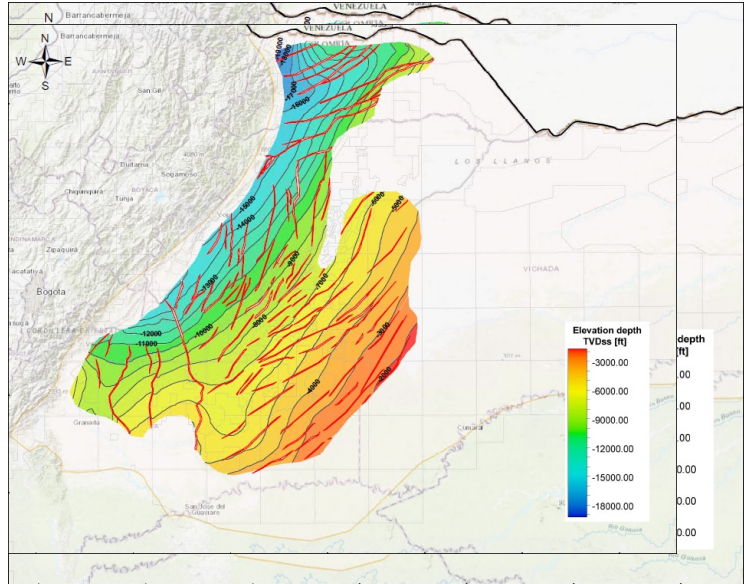


Seismic sections Phase 3

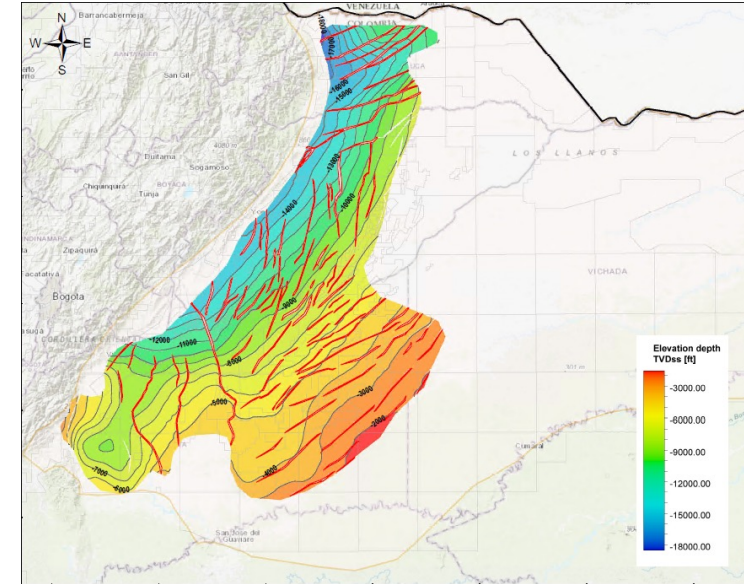


Paleozoic distribution

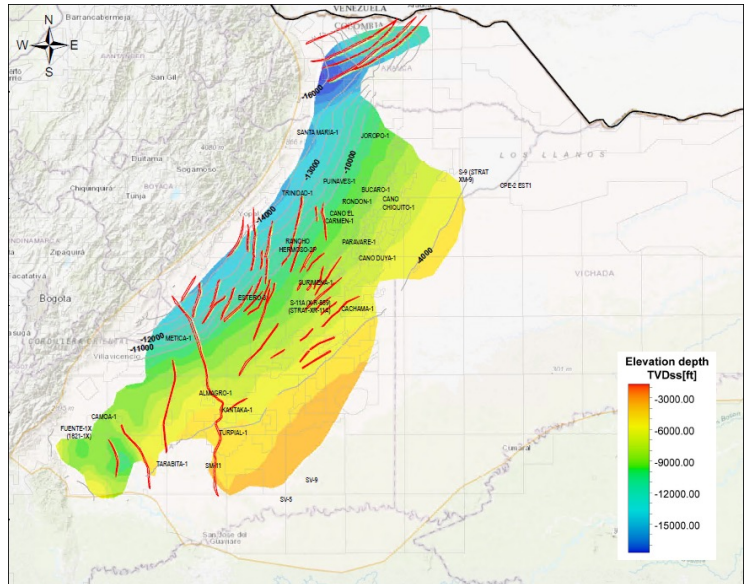
Cambrian



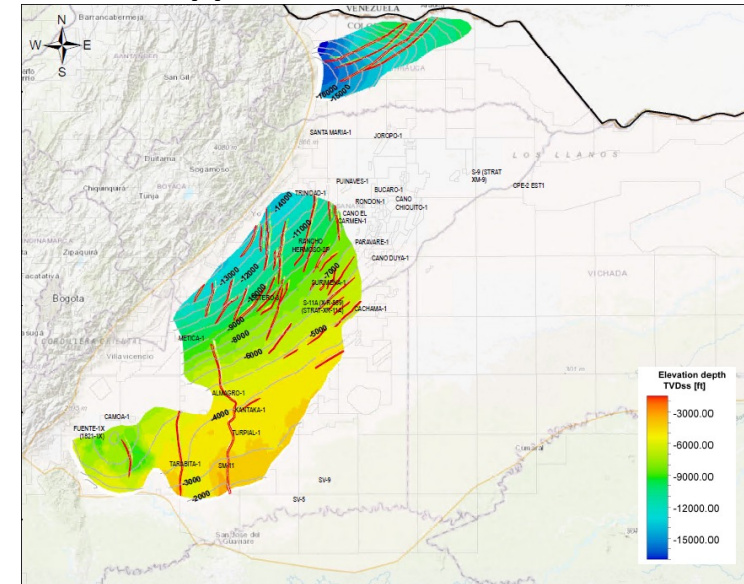
Lower Ordovician



Middle Ordovician

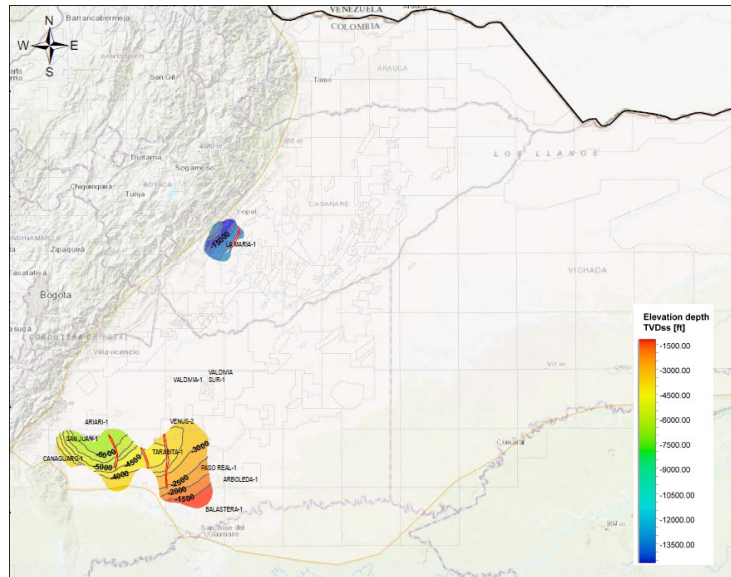


Upper Ordovician

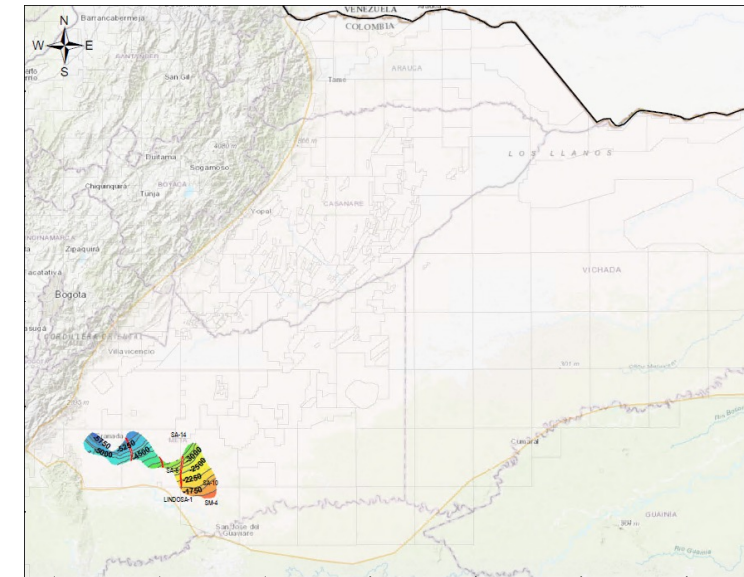


Paleozoic distribution

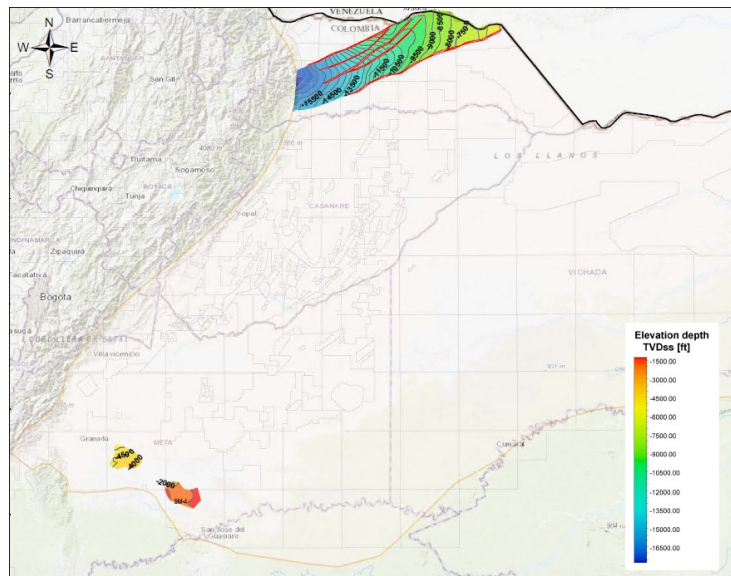
Siluric



Devonian



Carboniferous



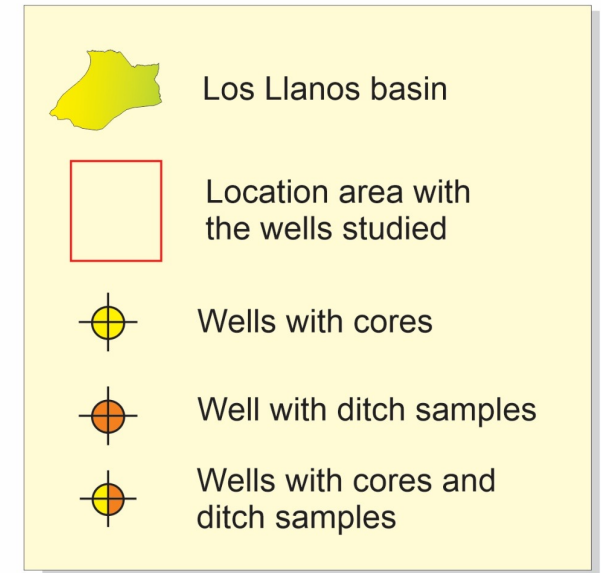
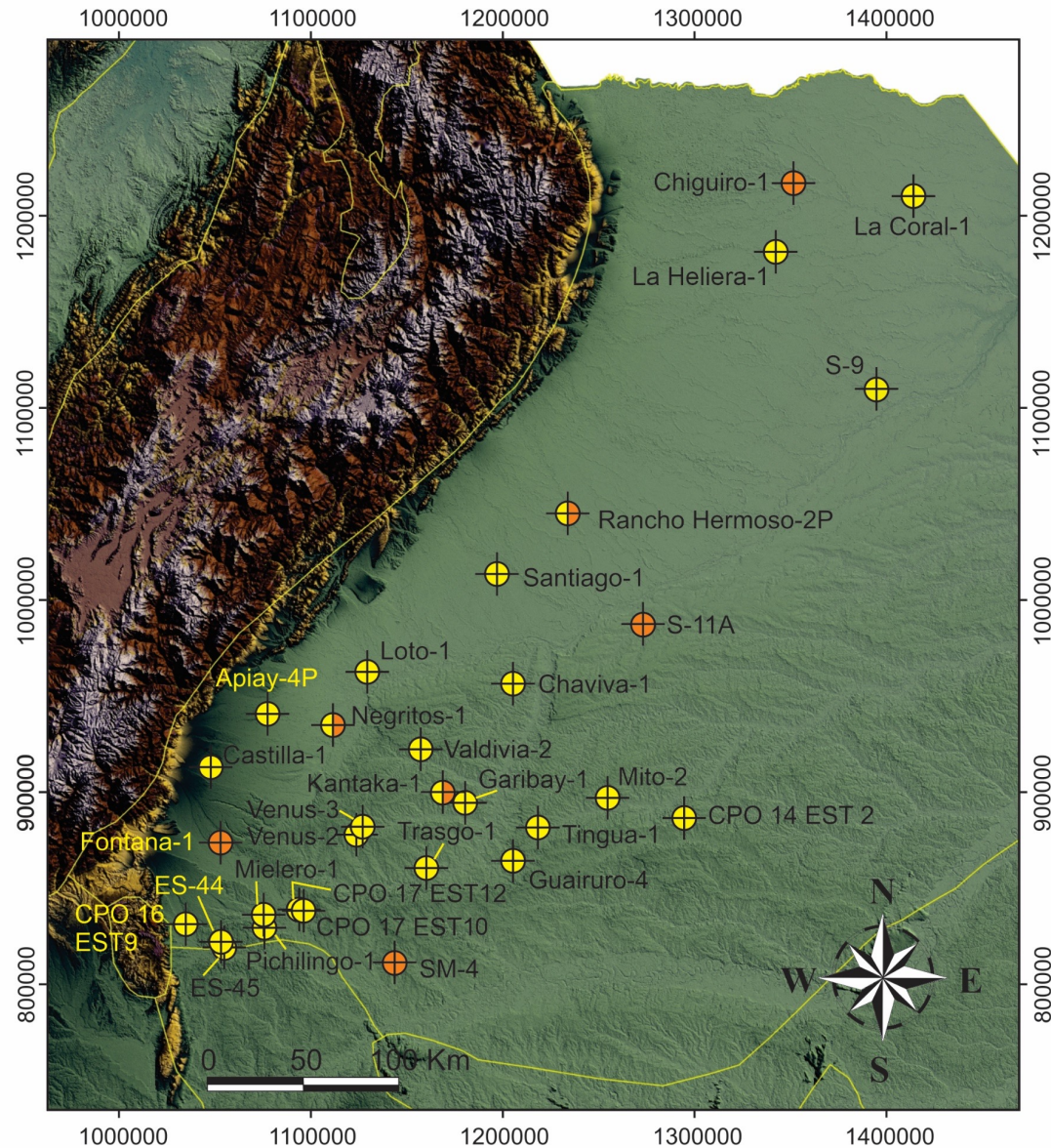
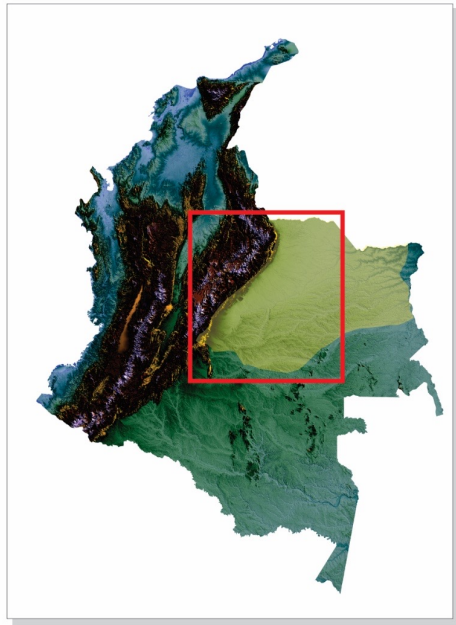
Wells Information (Cores and Cuttings)

Well information (31 Wells with Palaeozoic intervals): cores and cuttings (2019-2022)

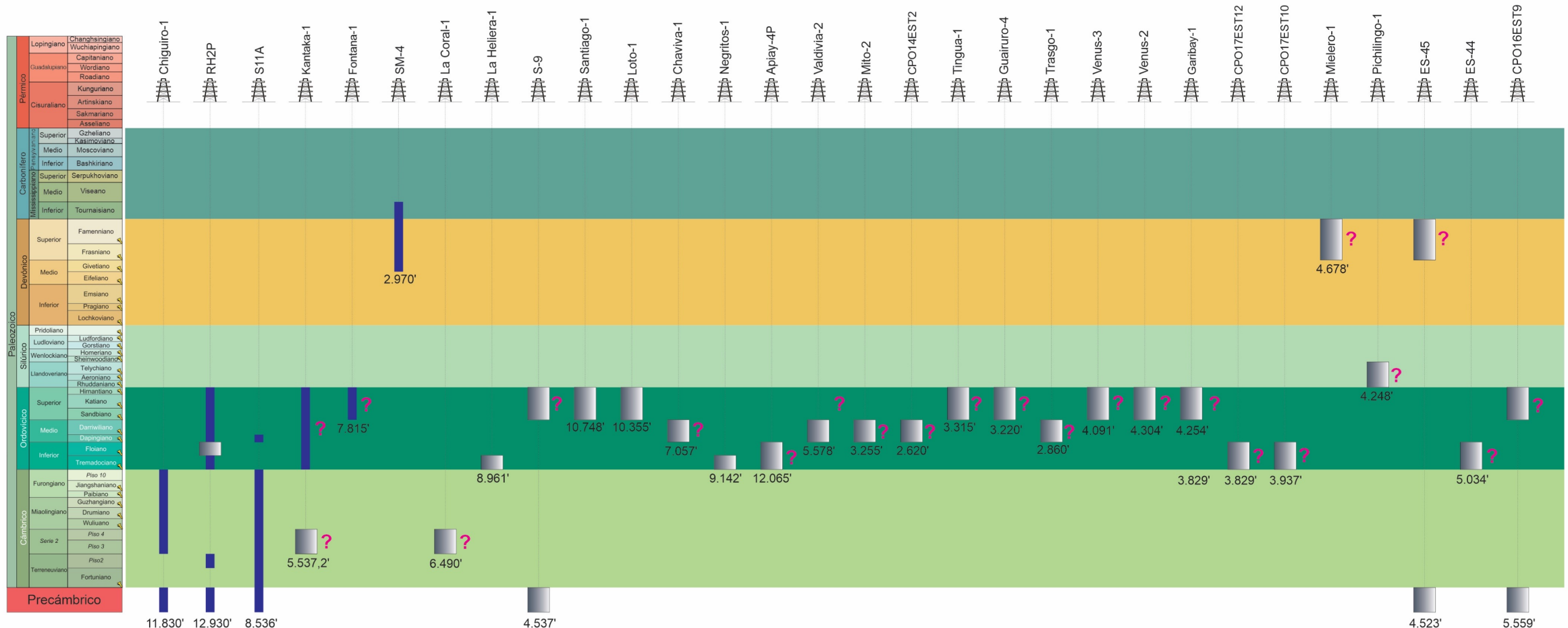
Preliminary results

- Biostratigraphy ages (no palynology results yet)
- Sedimentological models (constructed previously) are being refined with laboratory data (petrography, XRD, geochemistry, etc.)

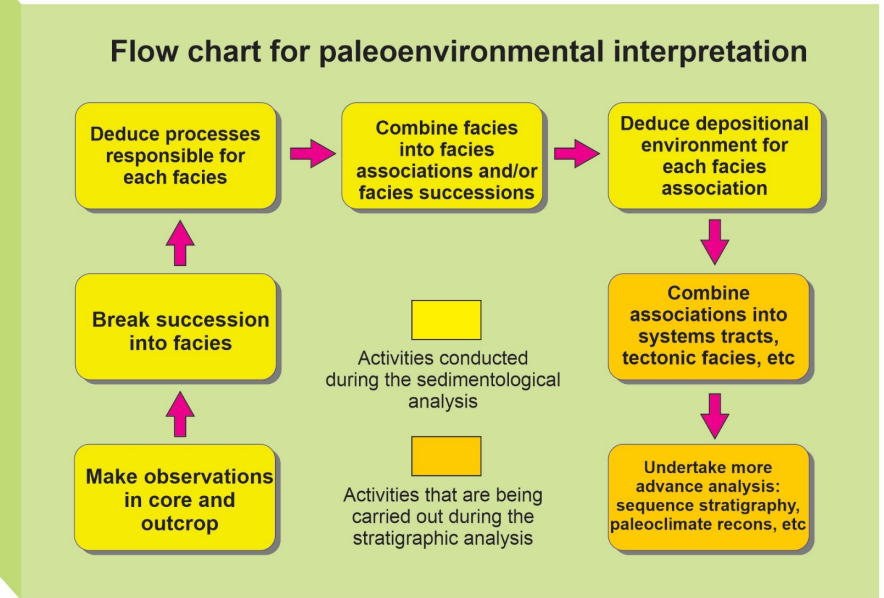
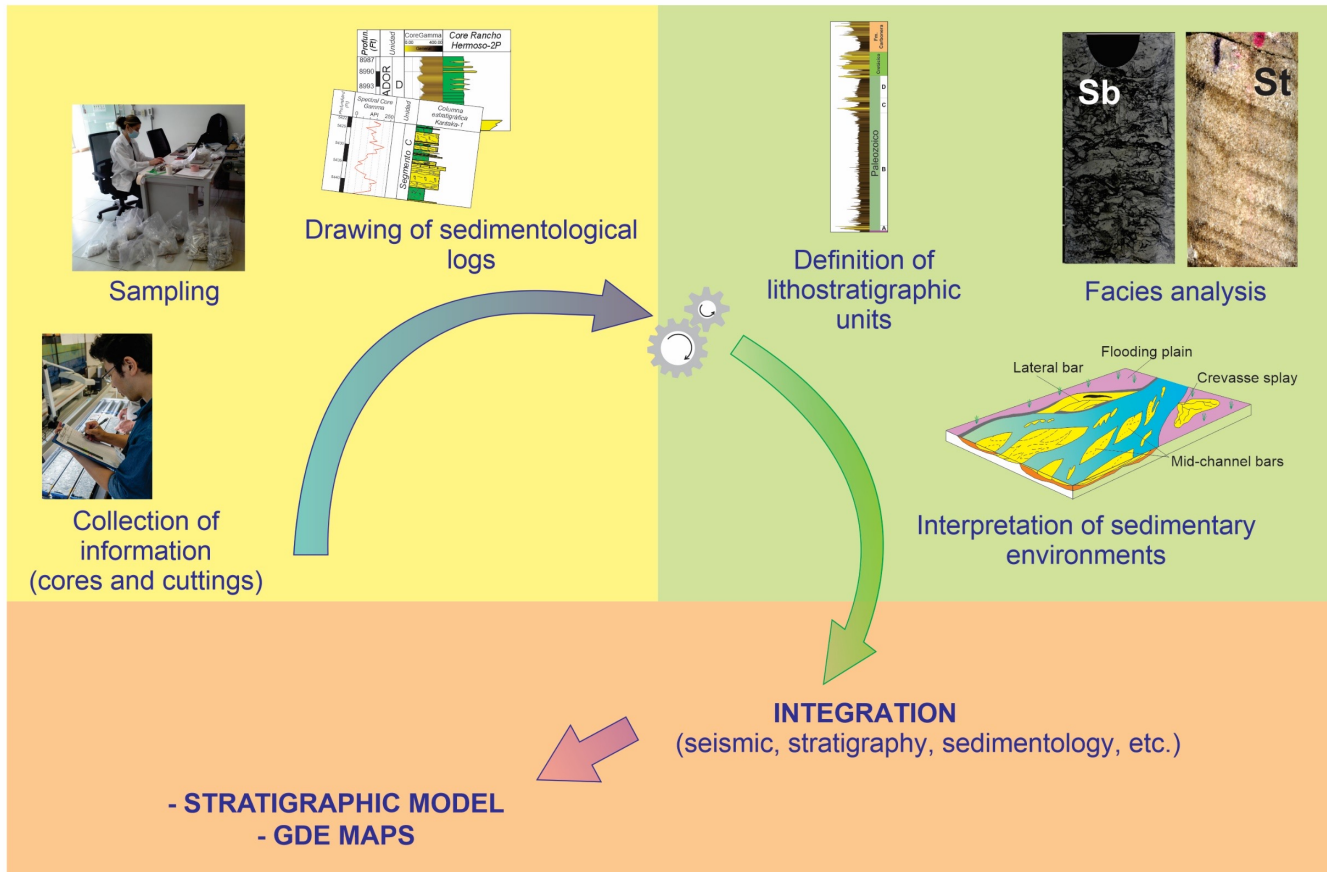
Location Of Wells Studied



Stratigraphic Position Of Intervals



Methodology



Dalrymple (2010)

- Activities of information collection and sampling
- Activities of sedimentological analysis (lithostratigraphy, facies analysis and paleoenvironmental reconstruction)
- Activities of integration and construction of regional models

Data

31 WELLS

27 cores and 6 wells with ditch samples (cuttings)

11.854 Ft of stratigraphic columns (length)
(1.388 Ft of cores and 10.466 cuttings)

1.557 samples
(685 cores and 872 cuttings)
petrography, mineralogy (xrd),
geochemistry, petrophysics, etc.

Laboratory results to date

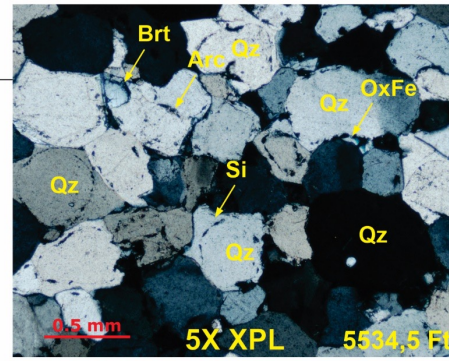
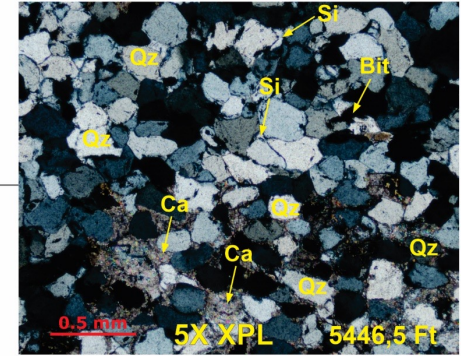
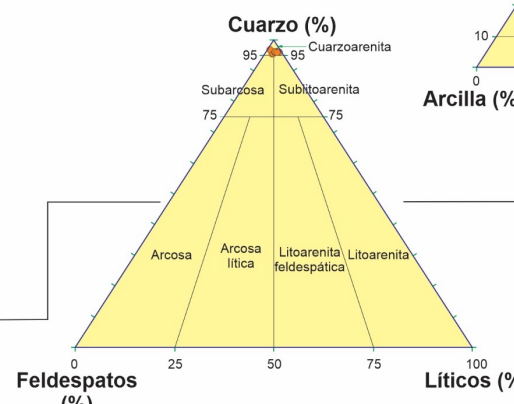
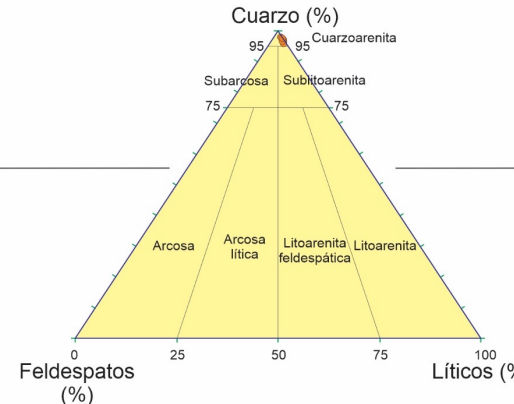
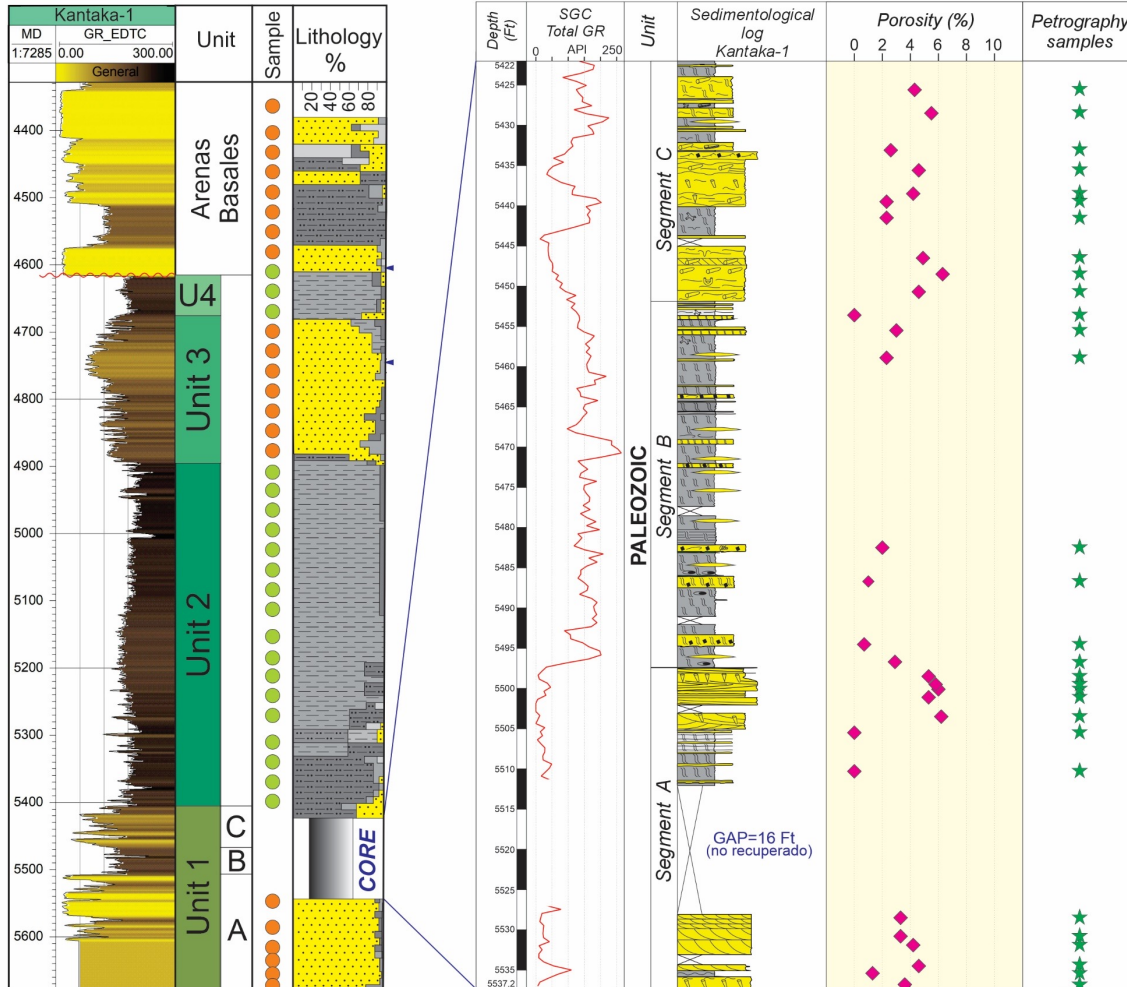
Petrography: 46 samples analyzed

XRD: 77 (preliminary) currently under revision

Organic geochemistry: 139 (preliminary)
currently under revision

Petrophysics: 51 plugs analyzed

Data: Integration To Sedimentological Analysis



◆ Percentages estimated in petrography (Convenio SGC-UNAL, 2020)

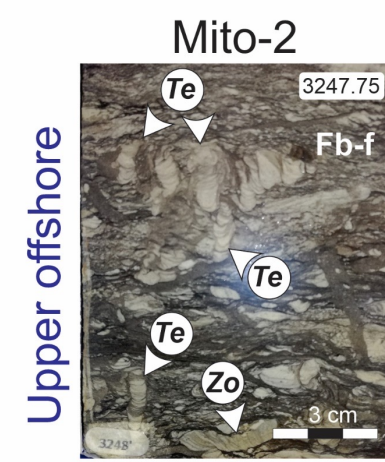
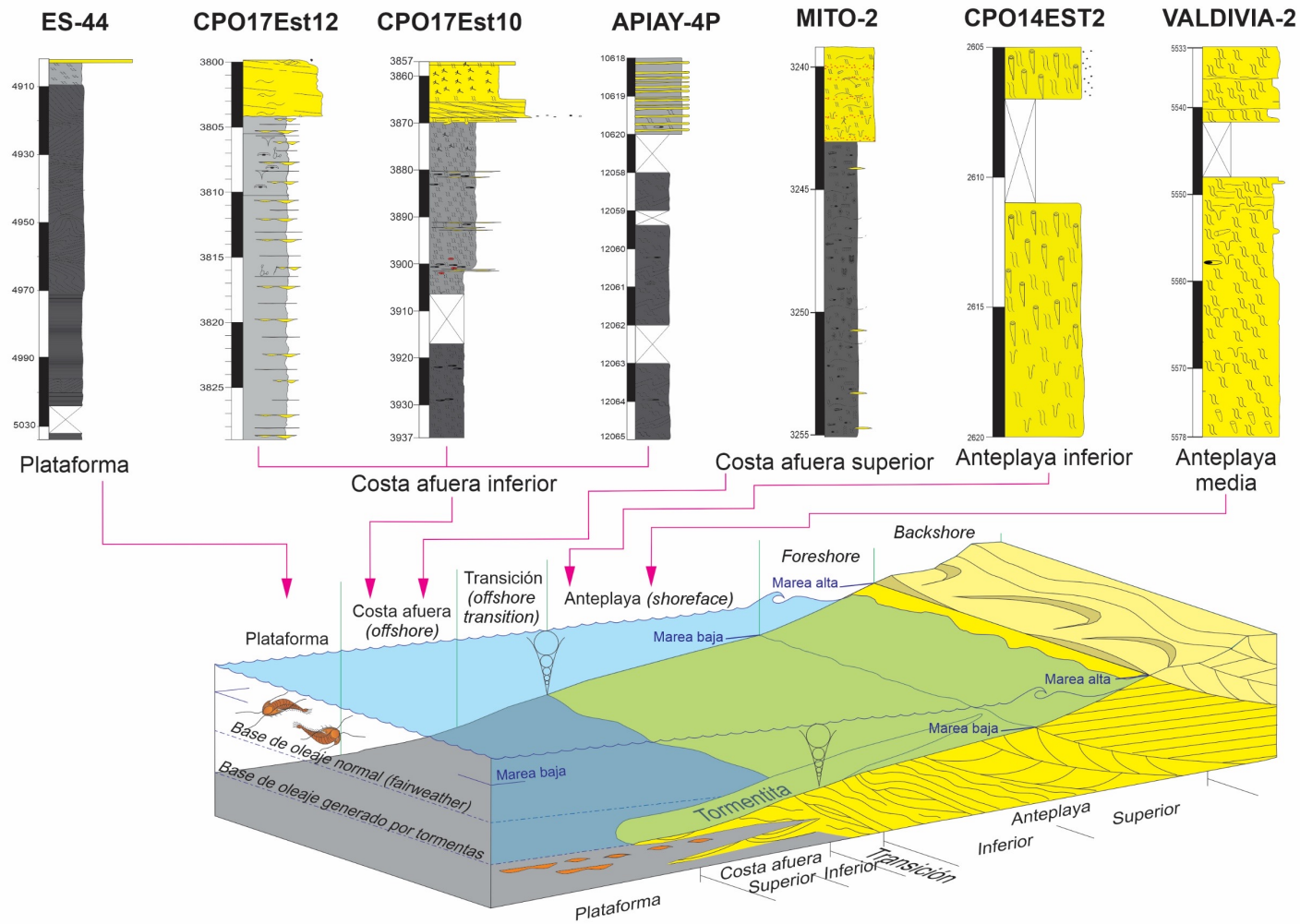
★ Petrography samples

● Petrography samples in ternary diagrams

Compositional classification (Folk, 1972)
Textural classification (Folk, 1954)

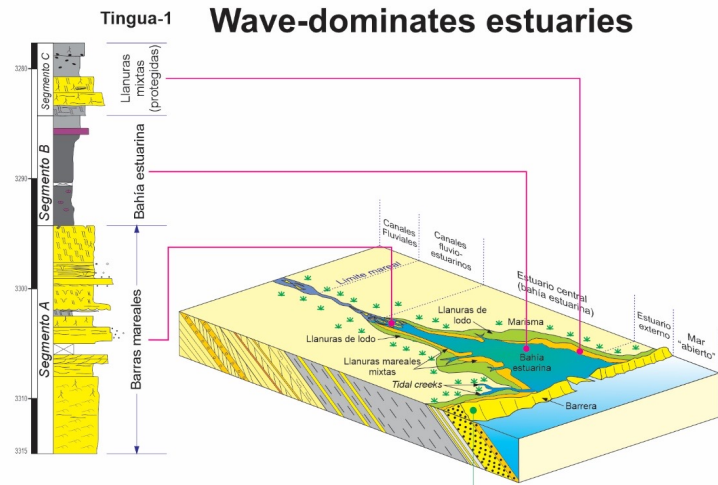
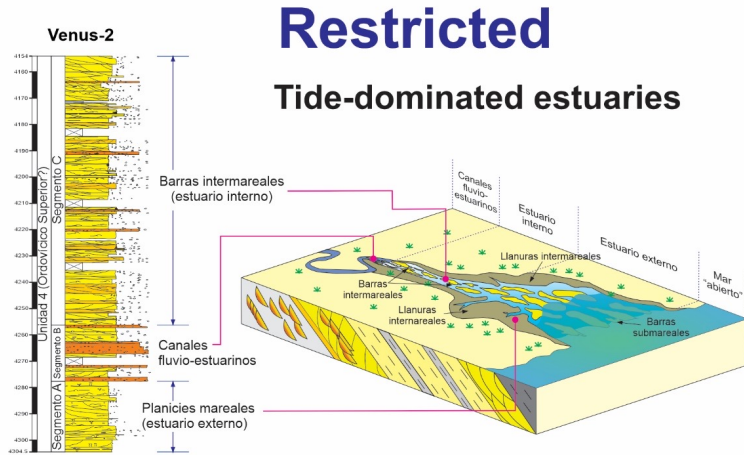
Results: Sedimentary Environments

Shallow marine environments



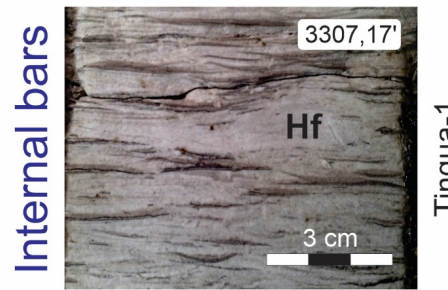
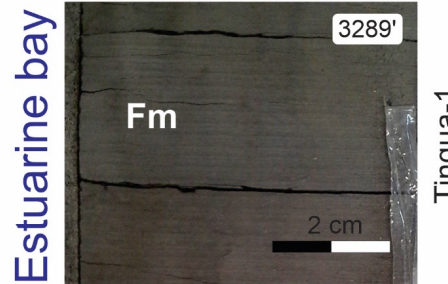
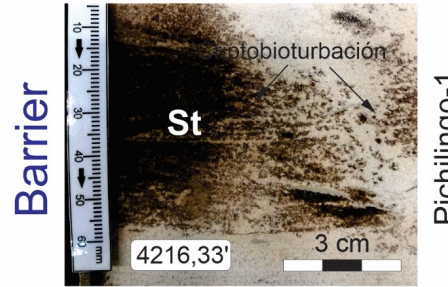
Results: Sedimentary Environments

Transitional environments



Isla barrera (elemento morfológico ausente en la sucesión estudiada)

Facies of wave-dominated estuaries

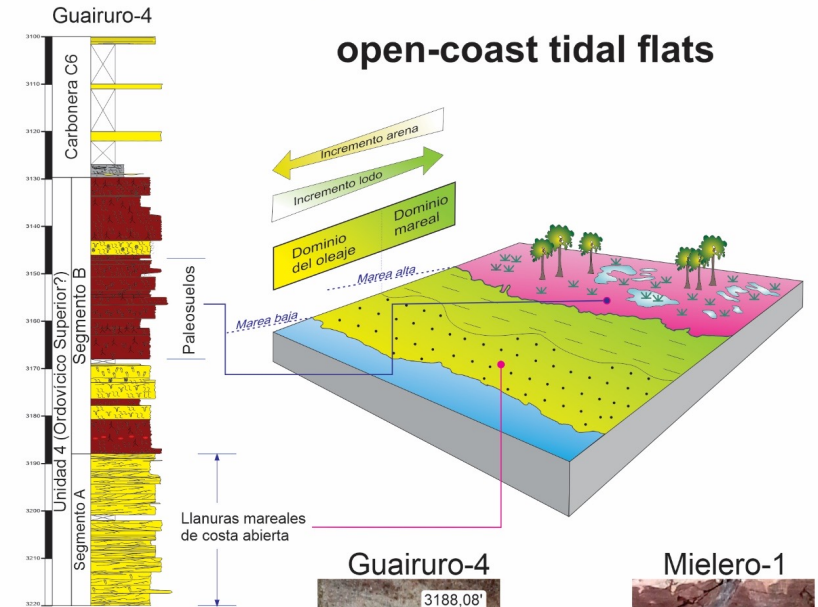


Pichilingo-1

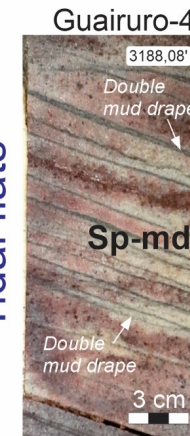
Tingua-1

Tingua-1

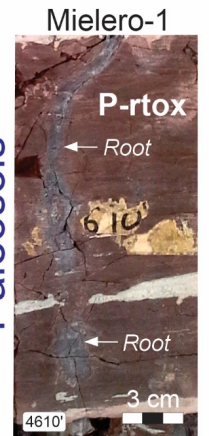
Open-coast open-coast tidal flats



Tidal flats

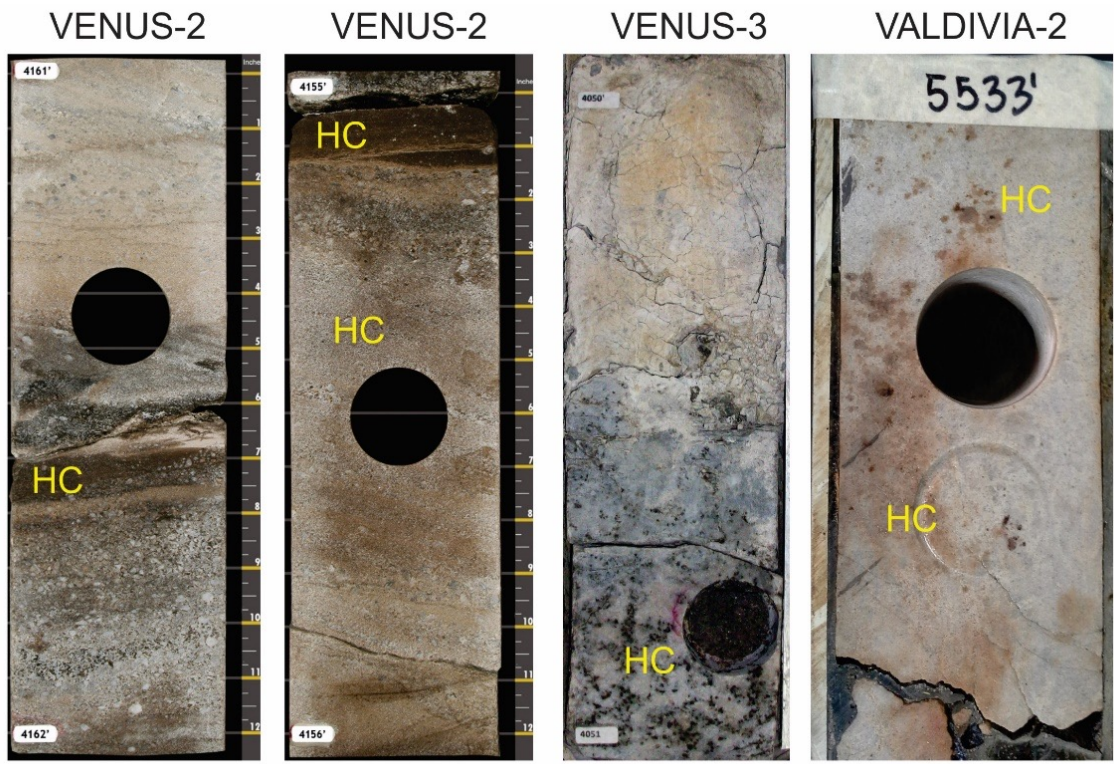


Paleosols



Interesting Findings

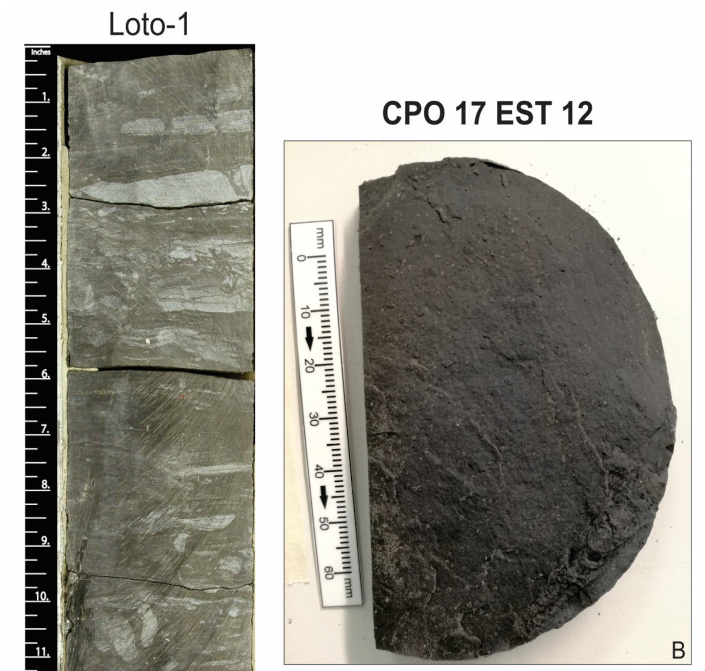
HYDROCARBON SHOWS



MACROFOSSILS



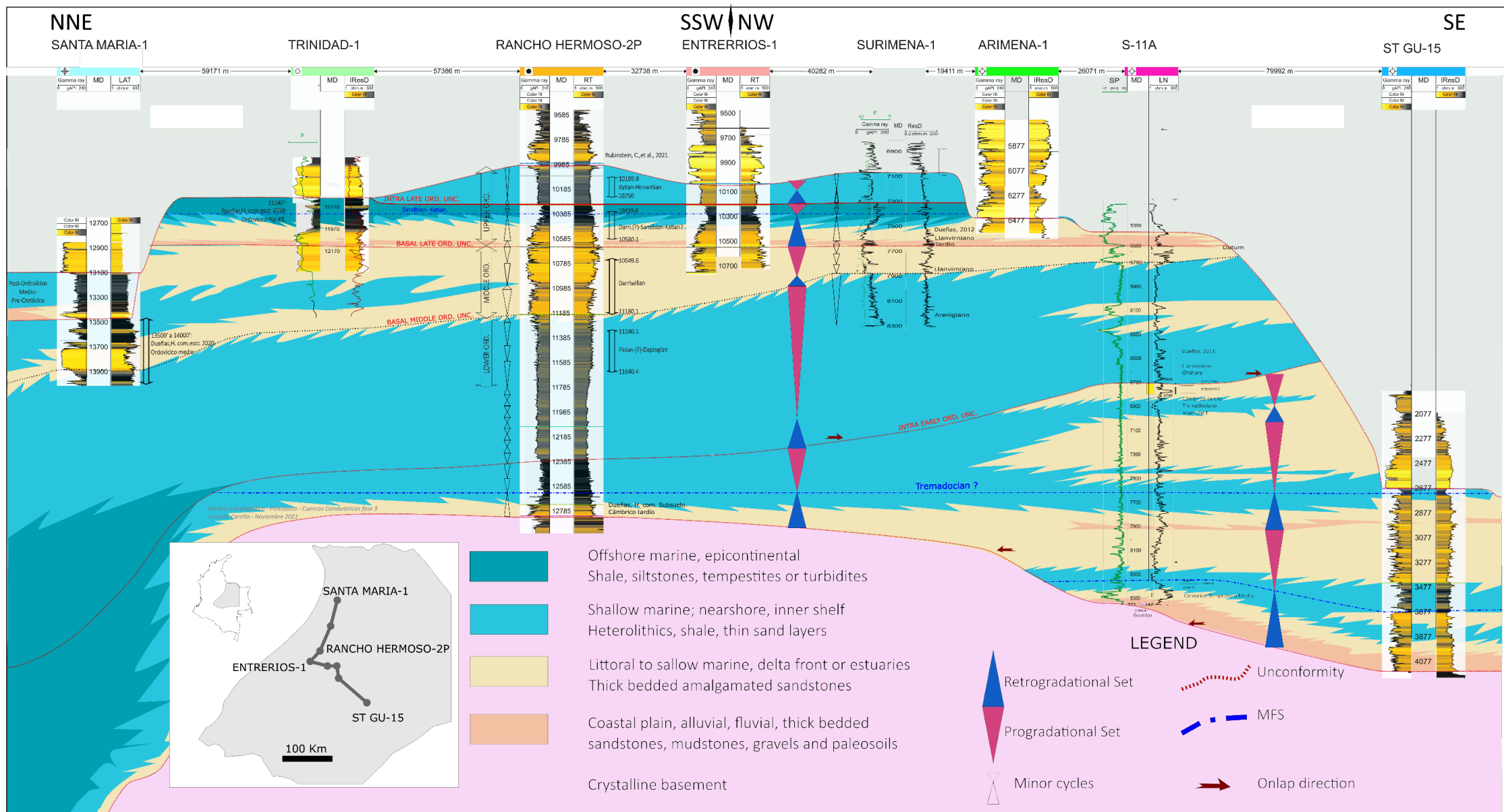
DARK FINE FACIES



Sedimentary Systems and Evolution

STRATIGRAPHIC MODEL - PALEOZOIC LLANOS BASIN

STRATIGRAPHIC CORRELATION SANTA MARIA-1 - ENTRERRIOS-1 - ST GU-15



Sedimentary Systems and Evolution

NW

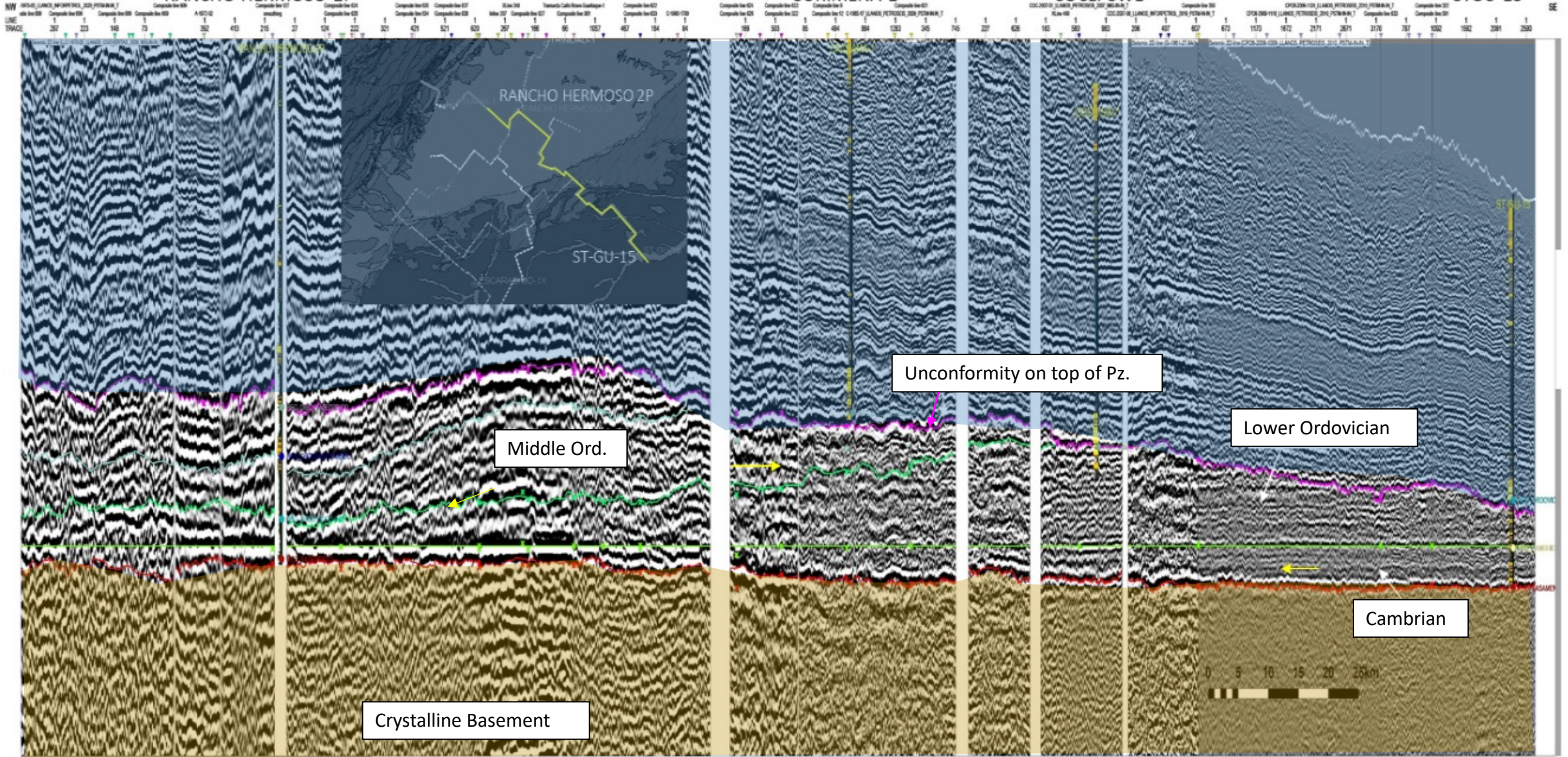
SE

RANCHO HERMOSO-2P

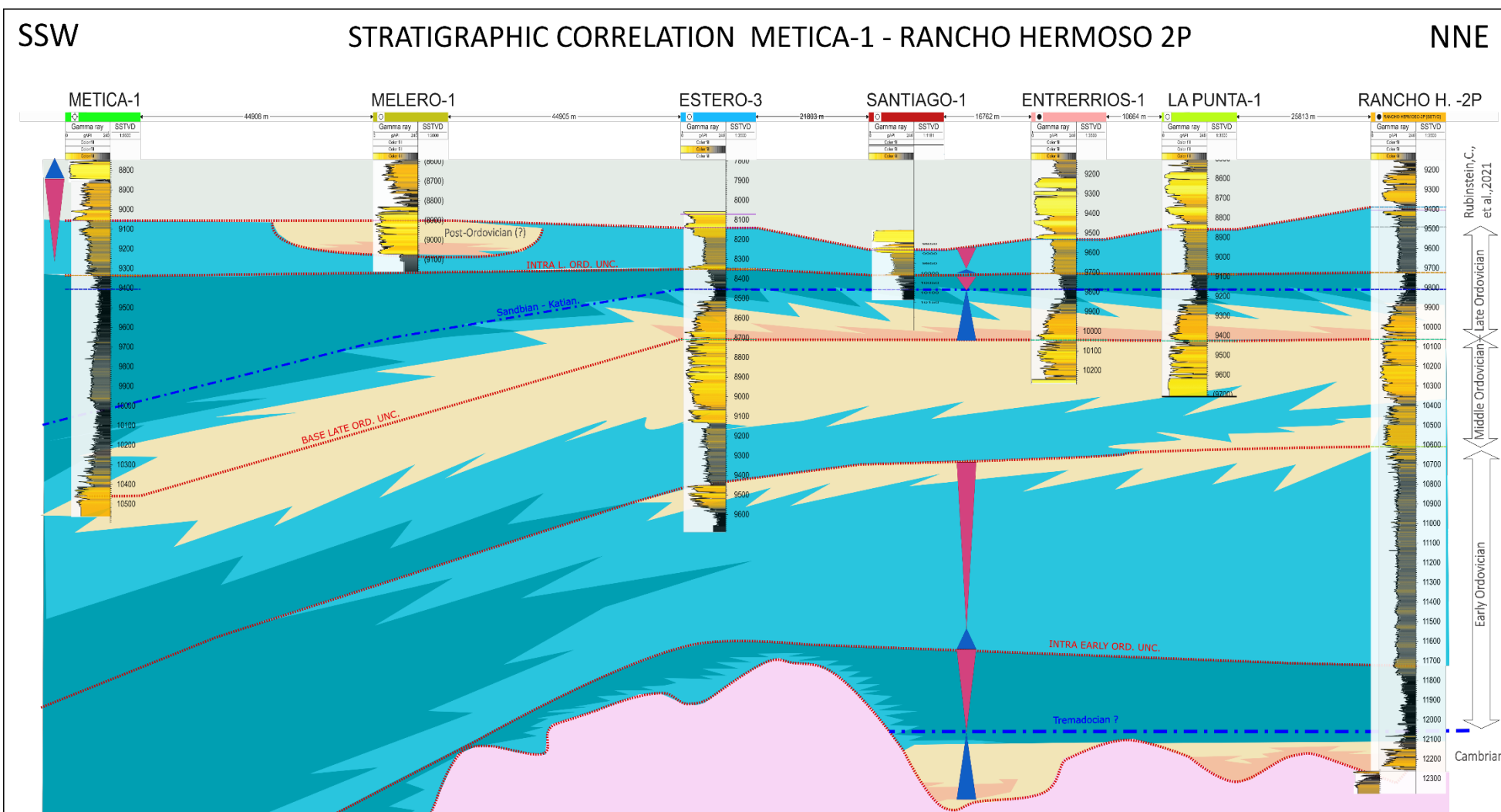
SURIMENA-1

COCLÍ-SW1

STGU-15



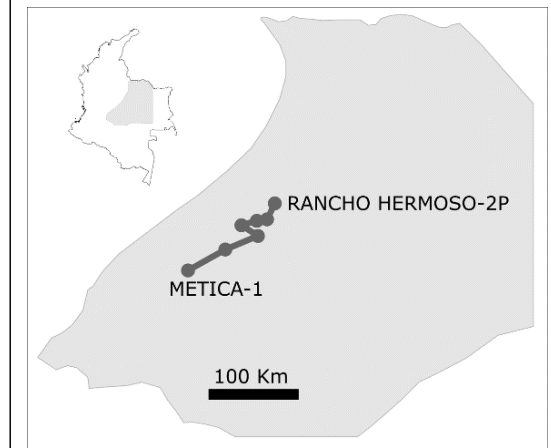
Sedimentary Systems and Evolution



LEGEND

- Retrogradational Set
- Progradational Set
- Minor cycles
- MFS
- Onlap direction
- Unconformity

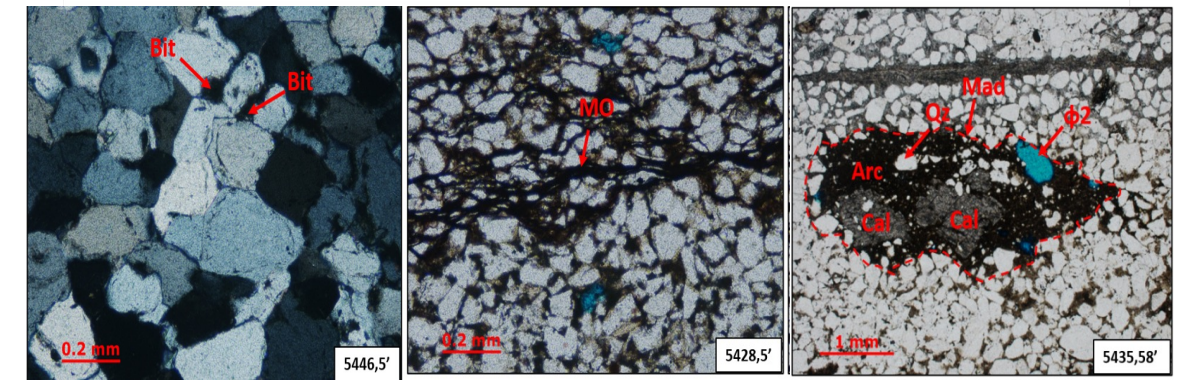
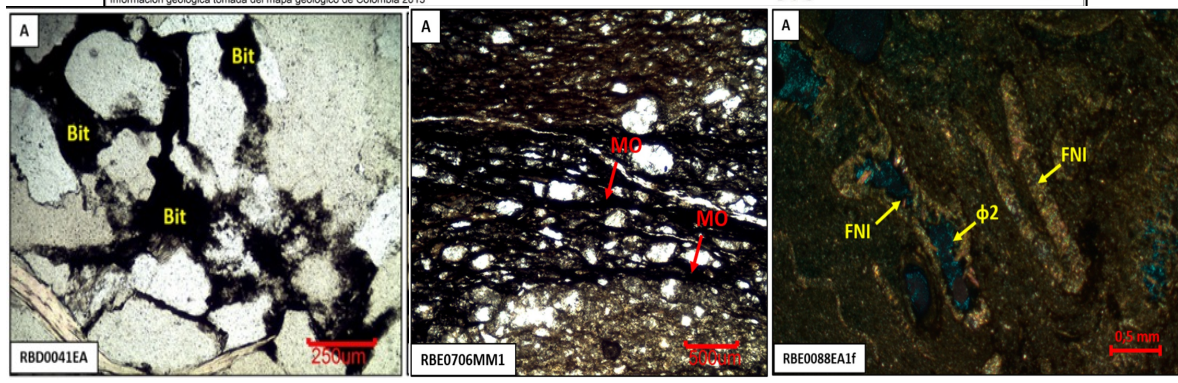
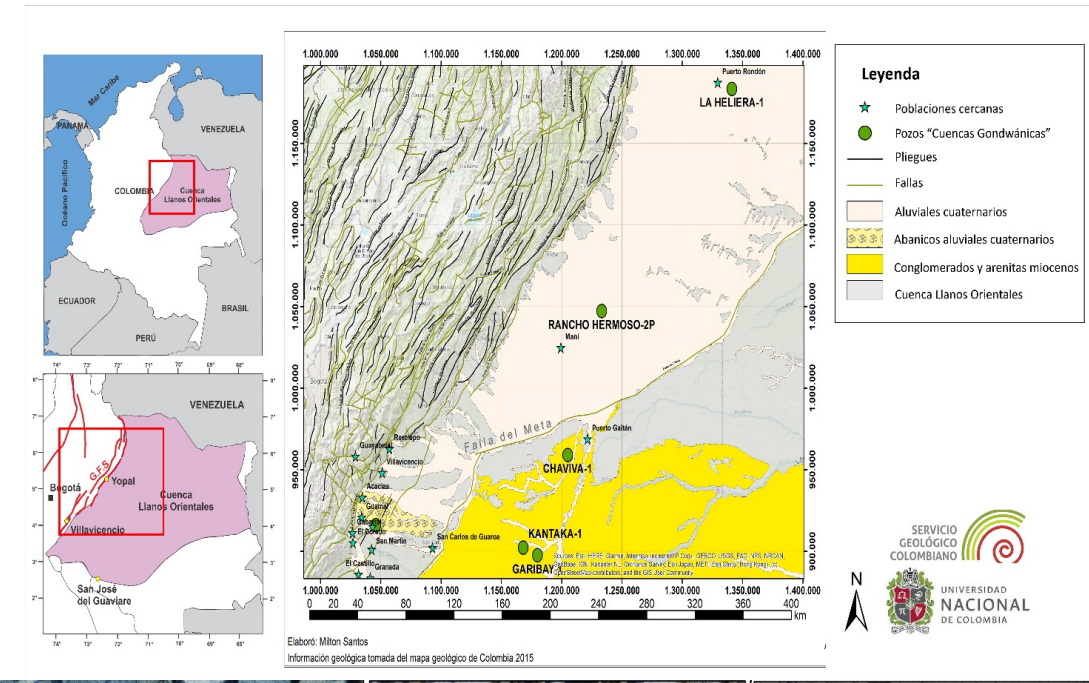
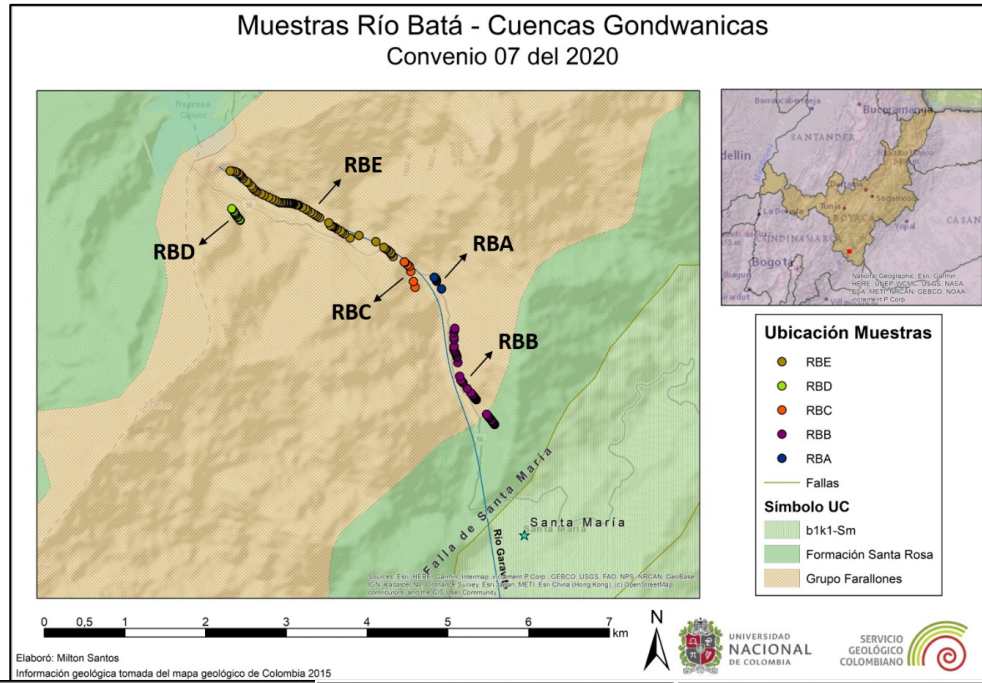
- Offshore marine, epicontinental
Shale, siltstones, tempestites or turbidites
- Shallow marine; nearshore, inner shelf
Heterolithics, shale, thin sand layers
- Littoral to shallow marine, delta front or estuaries
Thick bedded amalgamated sandstones
- Coastal plain, alluvial, fluvial, thick bedded
sandstones, mudstones, gravels and paleosols
- Crystalline basement

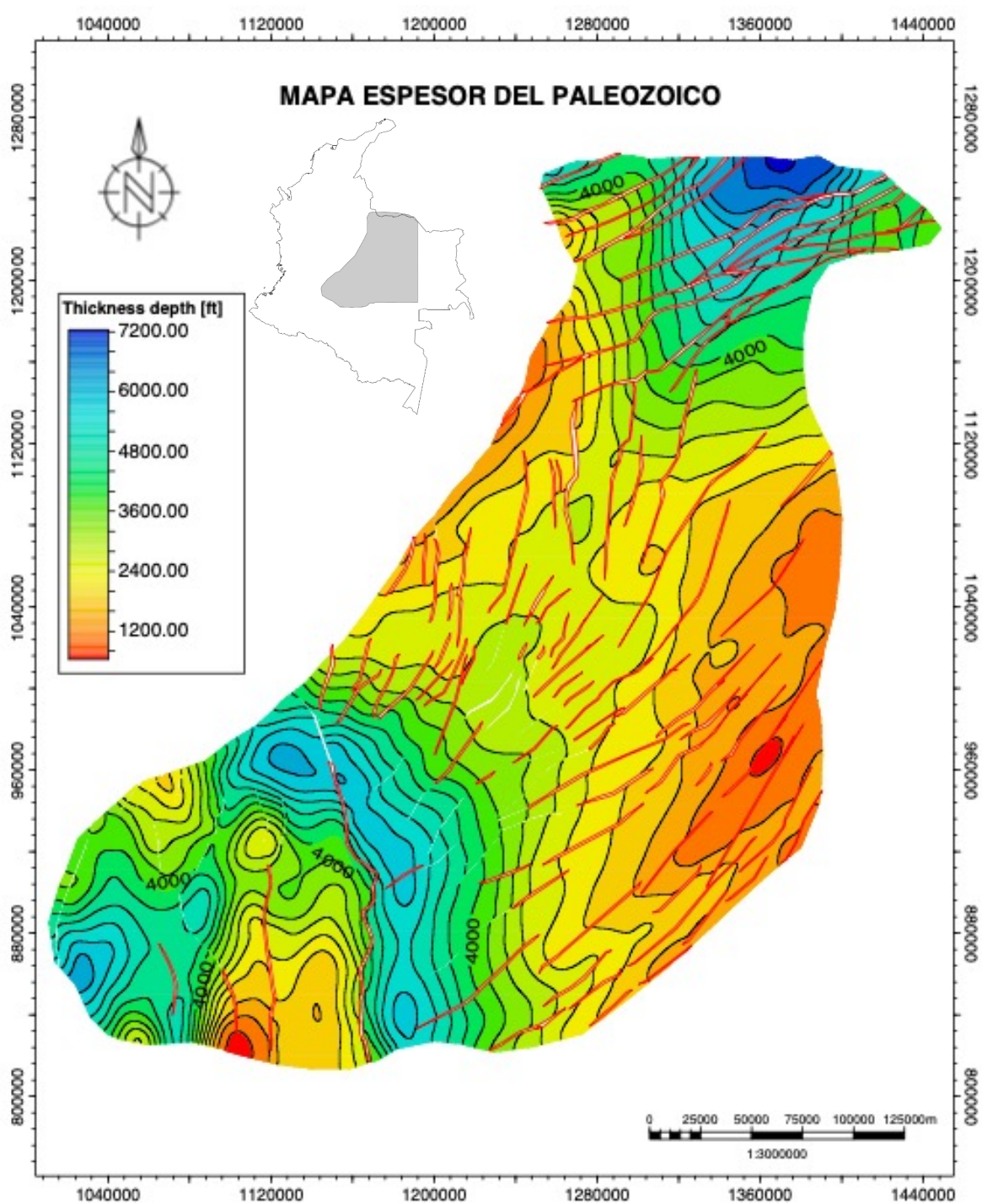


WHAT HAS BEEN DONE? LAB ANALYSIS

Lab Analysis of Rio Bata (Santa Maria – Boyaca)
154 samples were studied (U. NaI)

Lab Analysis of Cores and Cuttings
46 samples sent to lab for petrographic analysis





SOME FINDINGS
(How thick is the Pz ?)

SOME FINDINGS - Source Rocks

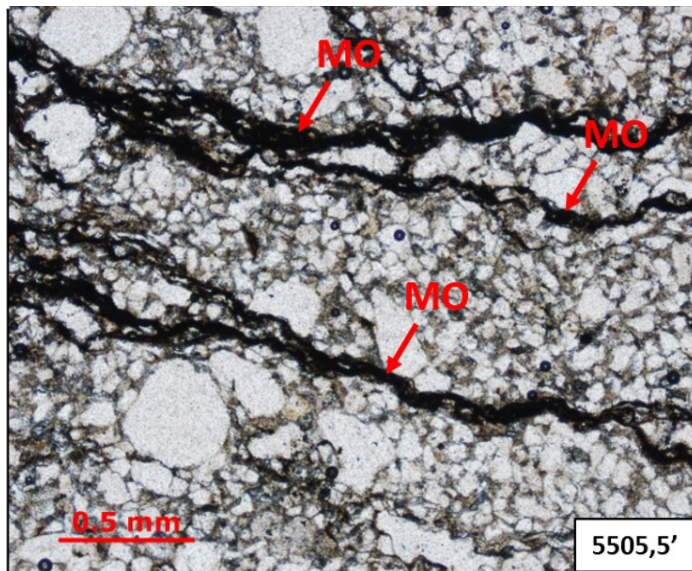
There are fossiliferous layers (cores, Surface samples, thin sections) (Lower Ordovician?, Carboniferous?, Silurian? Y Devonian?).

Black fine sediments (shales) were found in outcrops and cores

There is Organic Matter in outcrops and cores

Some cores and outcrops have Oil Stains within sandstones

From the available information, some wells to the south of the basin show low TOC's and high thermal maturity. Toward the north of the basin the thermal maturity is low



Layers of Organic Matter in Kantaka-1 well



Fossiliferous level in CPO17 EST 12. Trilobites (Lower Ordovician ?)



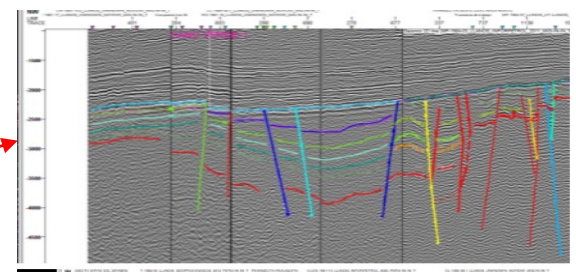
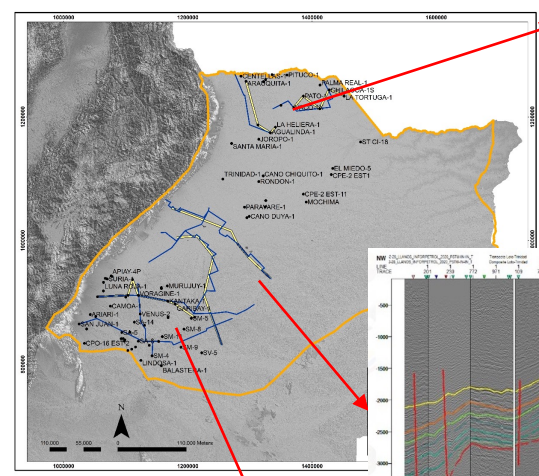
Fossiliferous level in Quebrada San Isidro (San Juanito-Meta).
Gastropods

SOME FINDINGS - Geometries & Traps

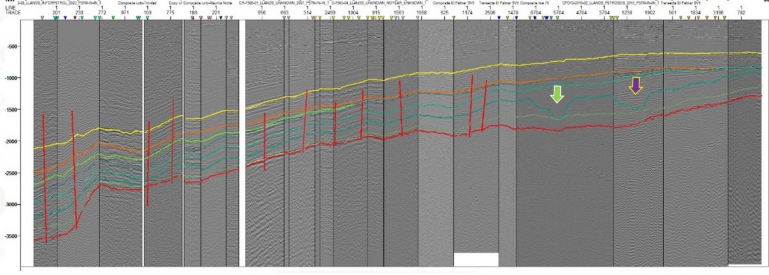
Interpreted Horizons (Cambrian, Ordovician, Silurian, Devonian, and Carboniferous. Permian ?)

4 structural provinces have been identified in the basin

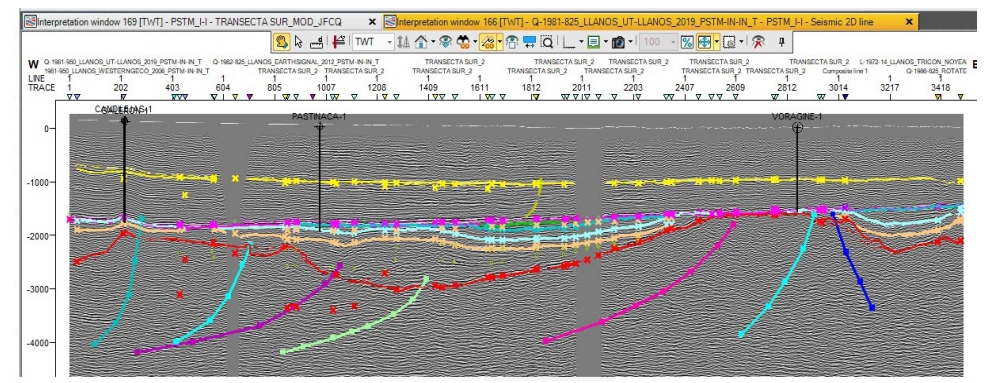
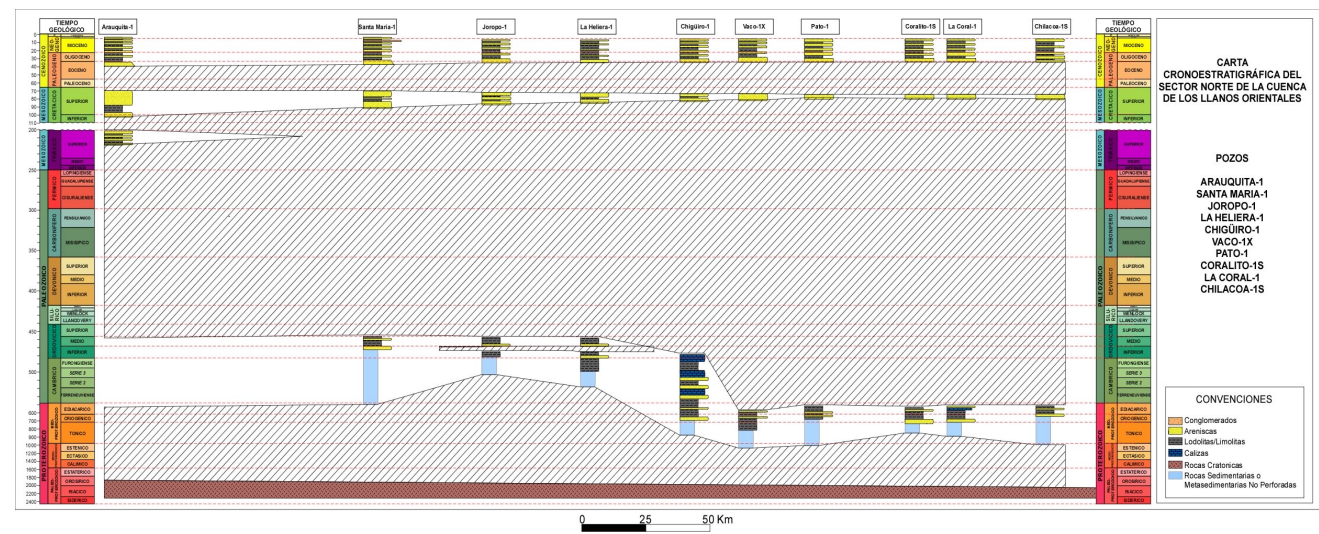
Palaeozoic has interesting geometries.



Arauca graben, filled with palaeozoic sediments



Some valleys and canyons at early Ordovician filled for mid Ordovician sediments.

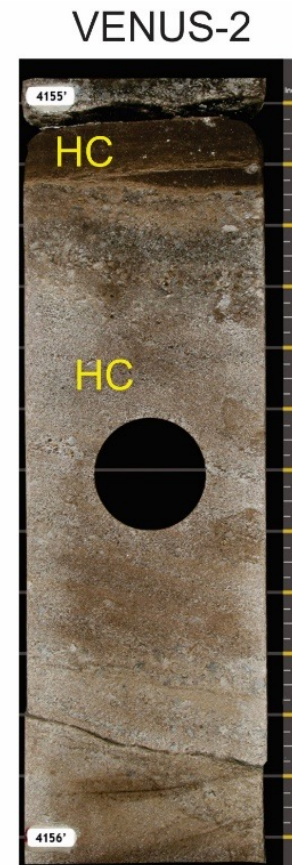
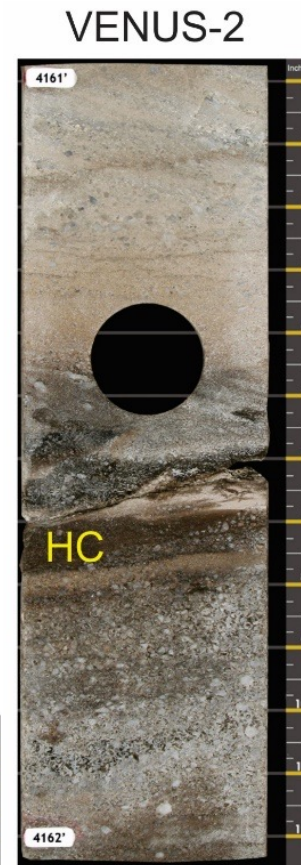
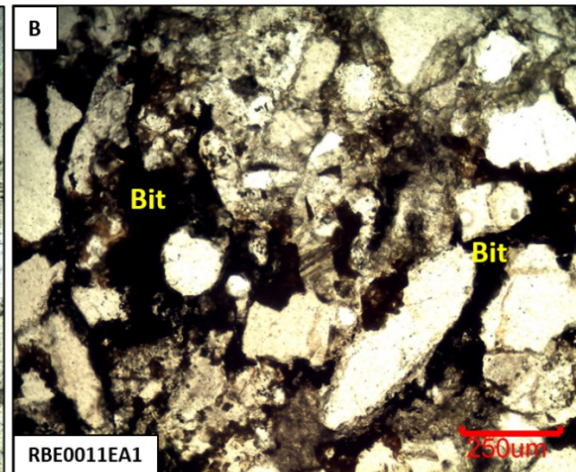
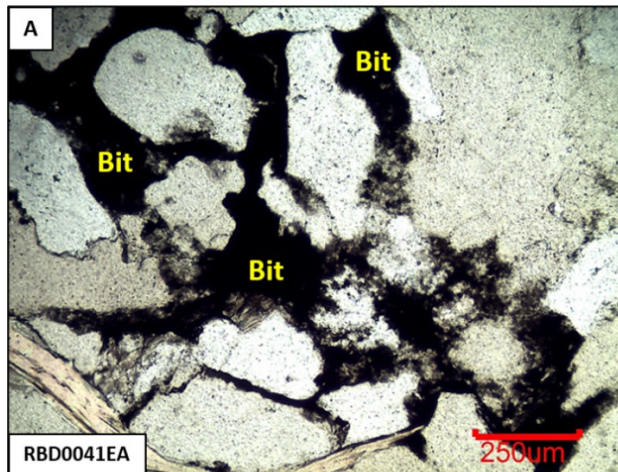


Greater distribution of the Ordovician and Silurian sequences

SOME FINDINGS - Migration

Thin sections have shown Bitumen

HC stains in cores



SOME FINDINGS - Reservoirs and seals

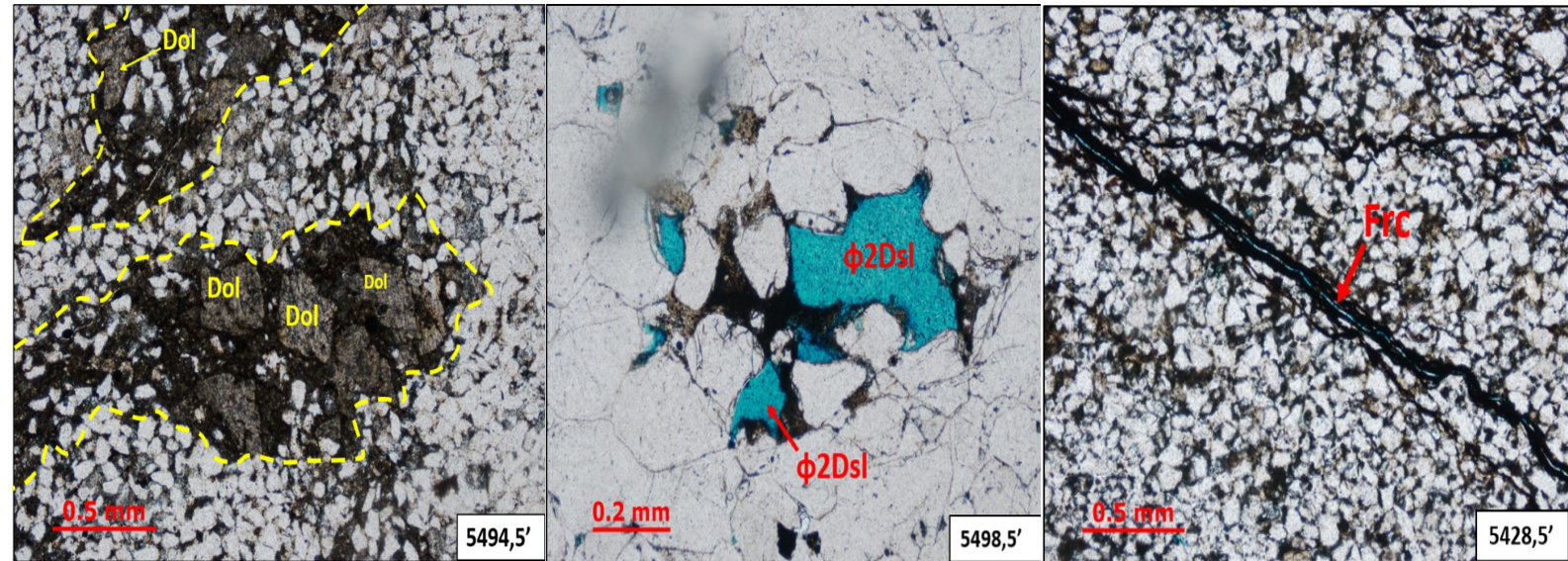
Petrography shows secondary porosity for different horizons in the Palaeozoic (Rio Bata and Cores)

In Surface the outcrops show intense deformation and fracturing (i.e. Quebrada La Cristalina)

Thin sections shows dolomitization processes, increasing the porosity



Limestones in Qbda La Cristalina




Secondary porosity due to Dolomitization, Dissolution and Microfracturing

OTHER INTERESTING FINDINGS


In Ariari area has been proposed a faulted contact between the gabbros and the palaeozoic limestones . The Surface team found evidence of the intrusive contact.

There are different types of gabbros emplaced (implications on maturation --- Barton M.)

In analysis of cores red sandstones and paleo soils have been found, similar facies to the ones found in Surface in Quebrada Pipiral, Quebrada El Diamante and Quebrada La Sapa



Relation between the gabbros and the palaeozoic limestones. Some xenoliths are visible within the gabbro



Unconformity Pz-Mz. Laguna La Esfondada – Parque Chingaza. 3604 msnm



Quebrada San Isidro (San Juanito – Meta)