THERMAL HISTORY OF EXHUMATION OF THE GARZON MASSIF AND THE EVOLUTION OF THE CAGUAN-PUTUMAYO BASIN

Presenters:

Dr. Alejandro Piraquive
Dr. Santiago León
Dr. Sebastián Jiménez

SGC-DAN

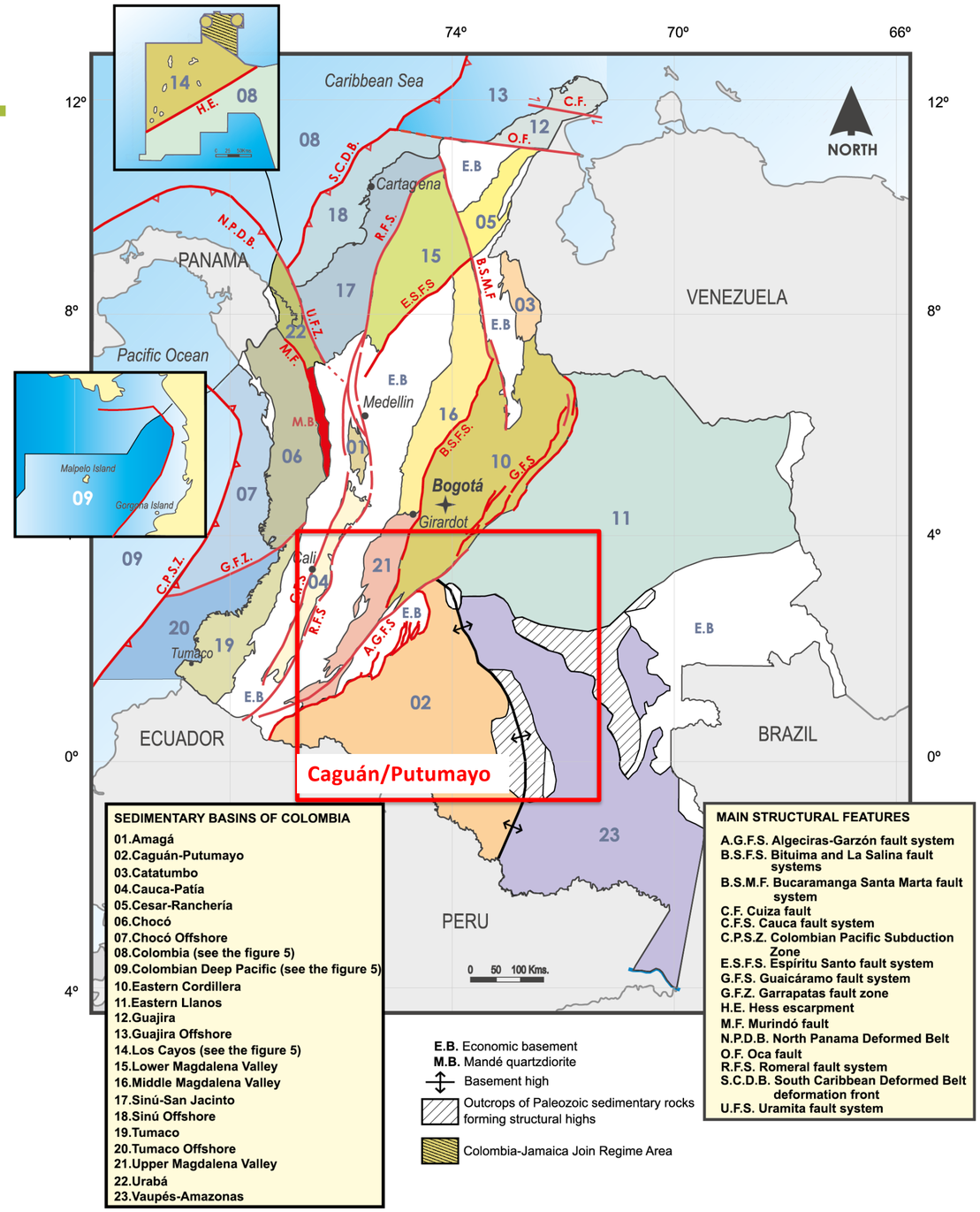
13/05/2022

SERVICIO GEOLÓGICO COLOMBIANO

El futuro es de todos | Minenergía

ANH AGENCIA NACIONAL DE HIDROCARBUROS

TABLE OF CONTENTS



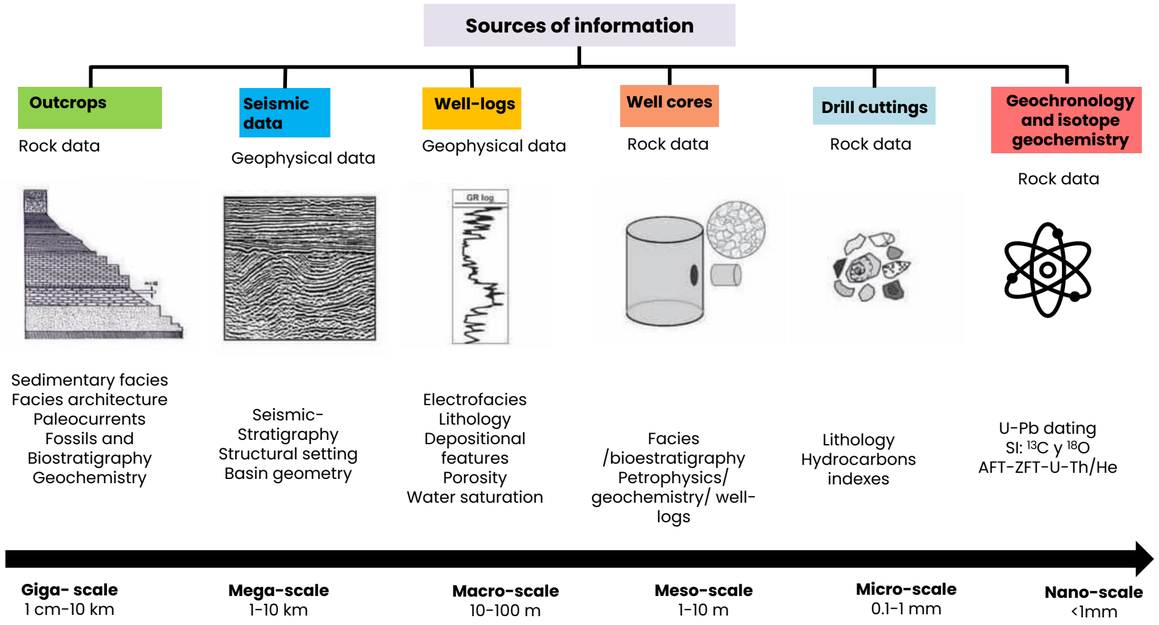
Mapa de Cuencas ANH Barrero et al., 2007

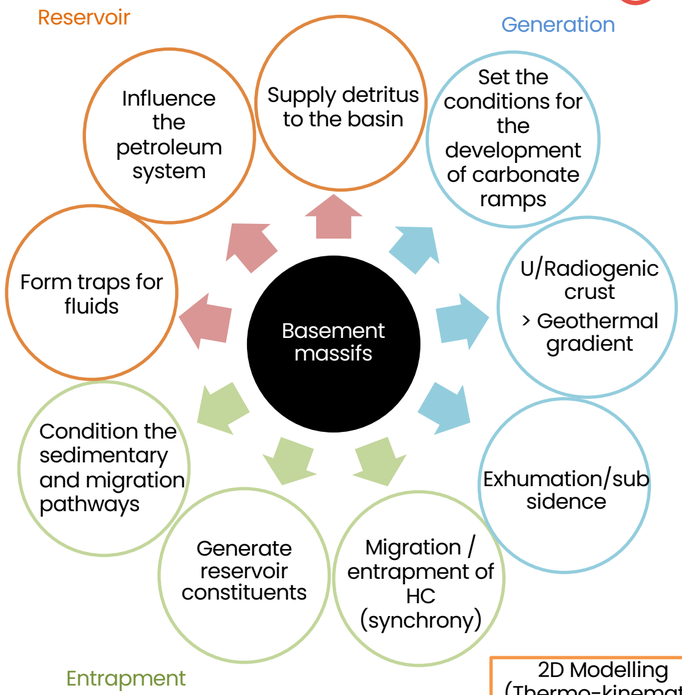
Methodological approach

The analysis of sedimentary basins integrates multi-scale information

The application of petro-thermochronological techniques provides a quantitative approach necessary (P-T-t-D-s) to reconstruct the paleogeographic evolution of a sedimentary basin

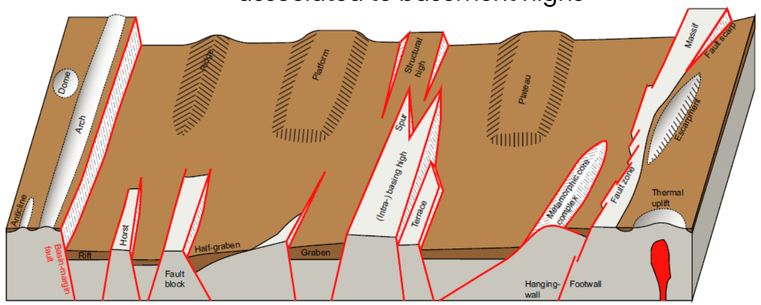
Such evolution involves the formation of both, stratigraphic and structural traps





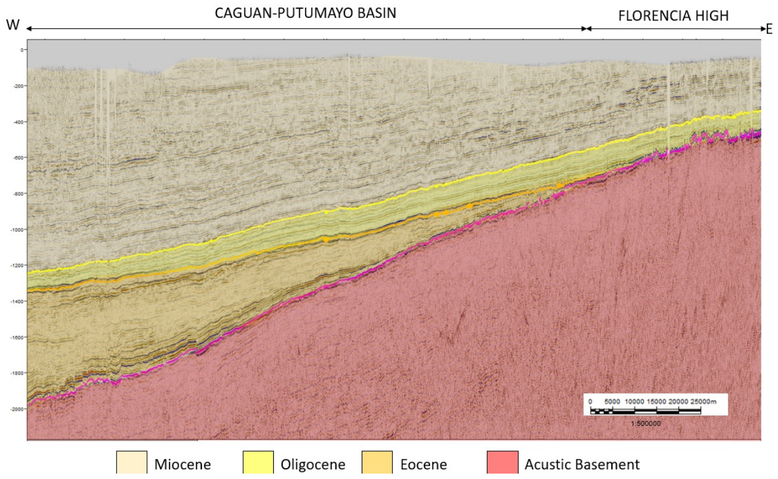
2D Modelling (Thermo-kinematic modelling)

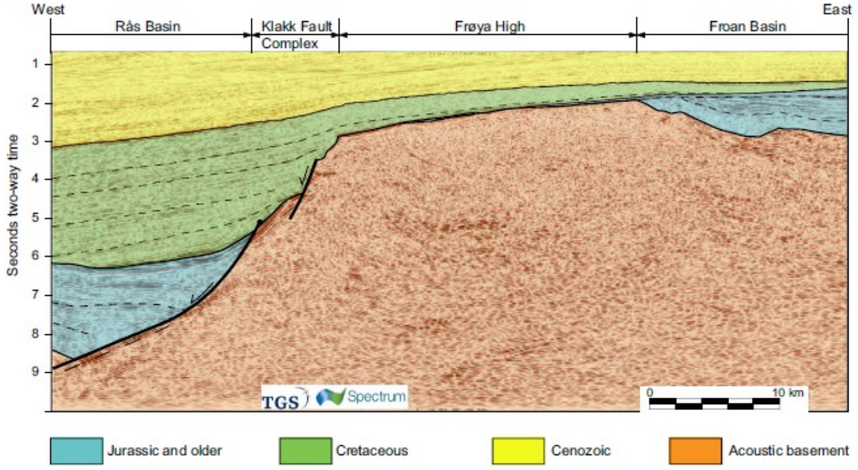
Structural and topographic features associated to basement highs



Peacock & Banks et al., 2020
Esrafili-Dizaji, 2021

Some examples of stratigraphic traps associated to basement highs

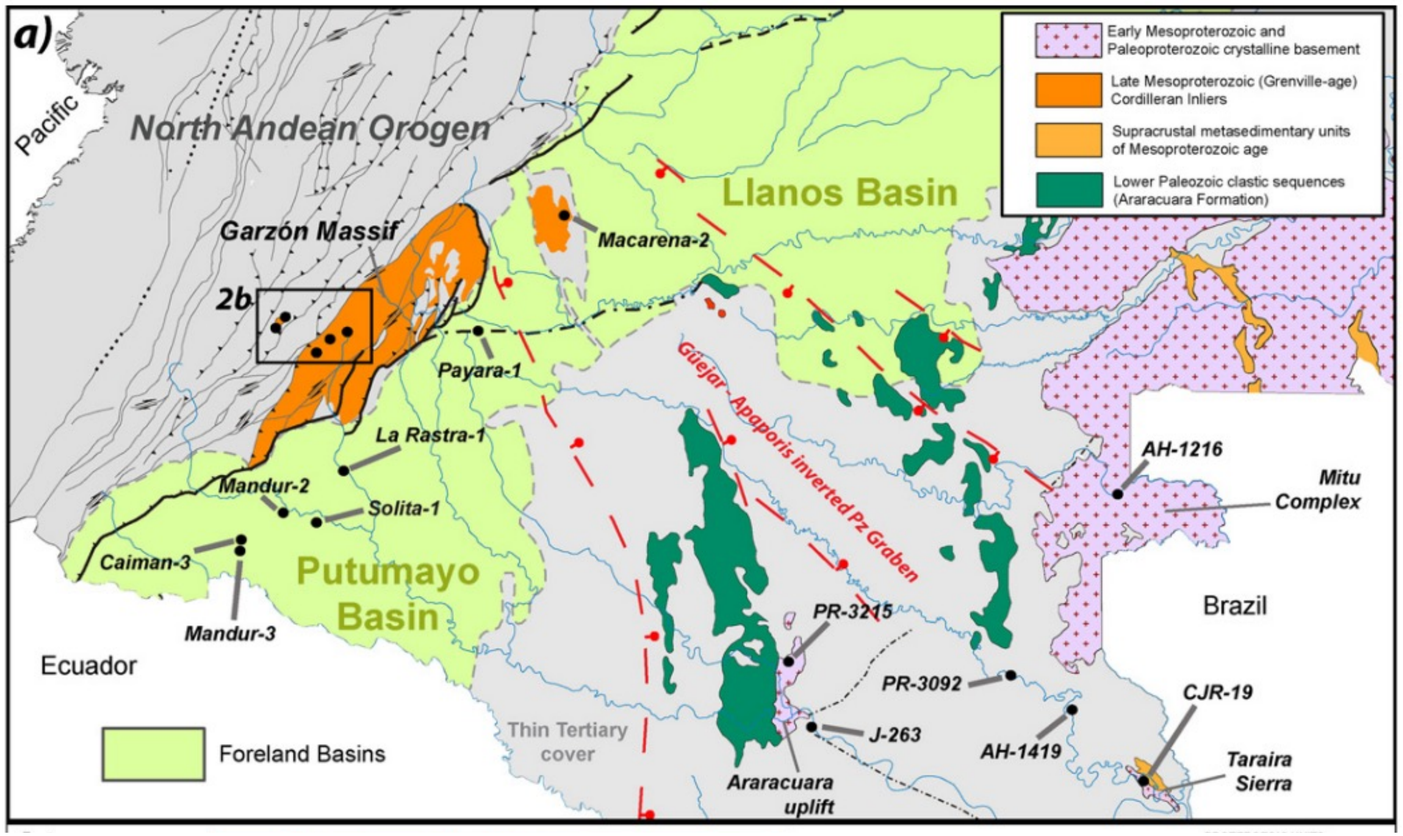




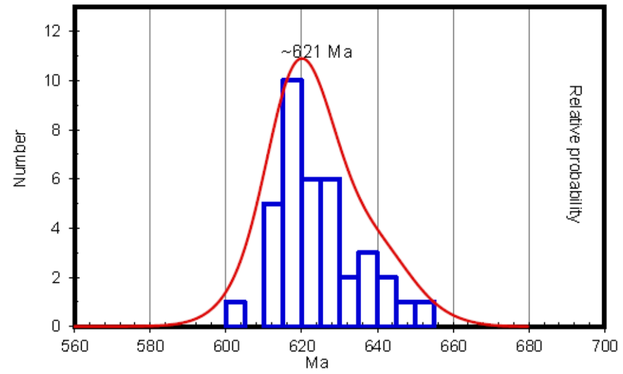
Regional Tectonic Setting

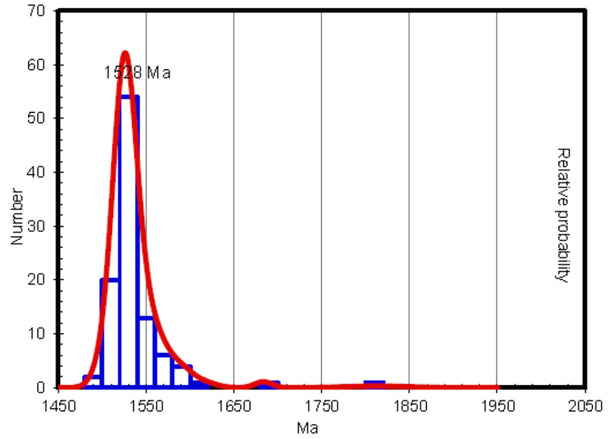
Caguán-Putumayo Basin-Garzón Massif

Regional Setting of the Caguán-Putumayo basin



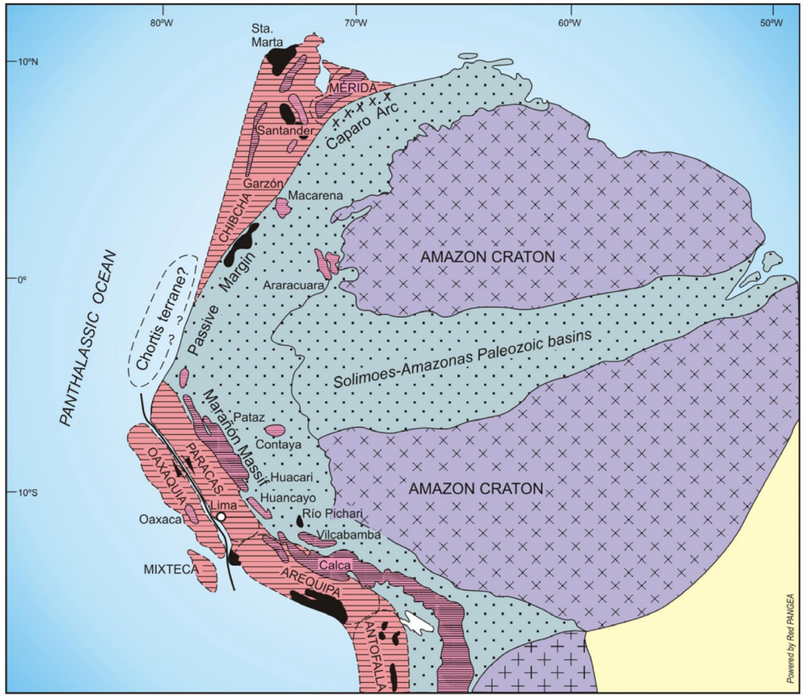
Ibañez-Mejía (2011)



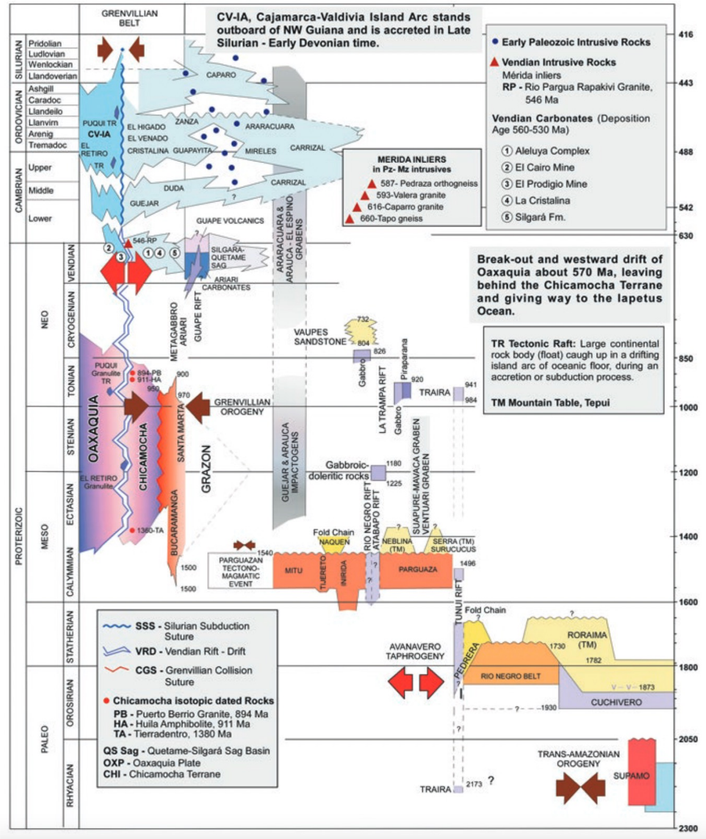


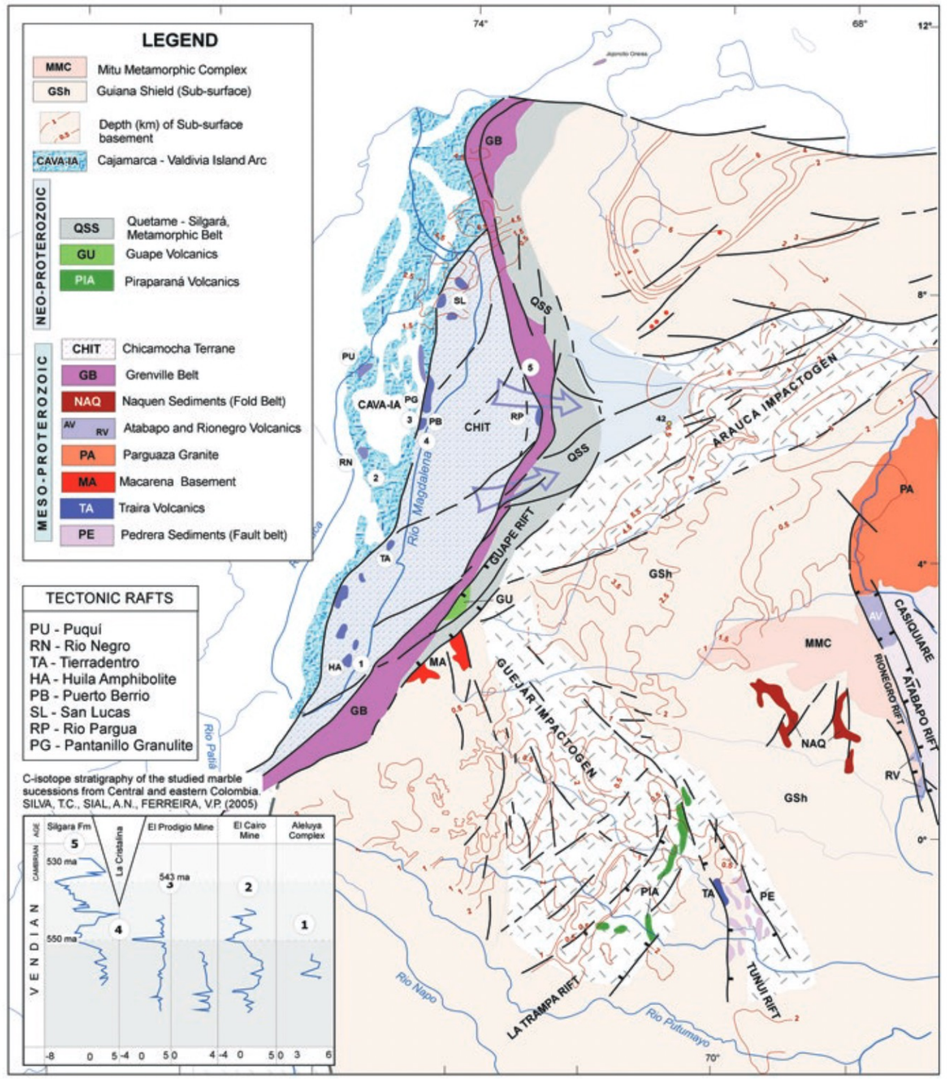
- **The geometry of the Caguán-Putumayo basin is controlled by structural highs denominated the Vaupés, Macarena, Florencia and Garzón highs.**
- **The Güejar-Apaporis inverted-graben preserves Paleozoic sediments that outcrop in the Eastern border of the basin**
- **The exposed portions of the shield and basement highs should have acted as sources of the sedimentary fill of the basin, these range in age from the Meso-Neoproterozoic (1500-900 Ma) and Ediacaran (700-600 Ma)**
- **The timing of exposure of these basement highs is largely unknown, and it has had a considerable influence in the sedimentary evolution of the Caguán-Putumayo basin during the Phanerozoic.**

Inherited Neoproterozoic Structures



Ramos (2010)
Cediel (2019)



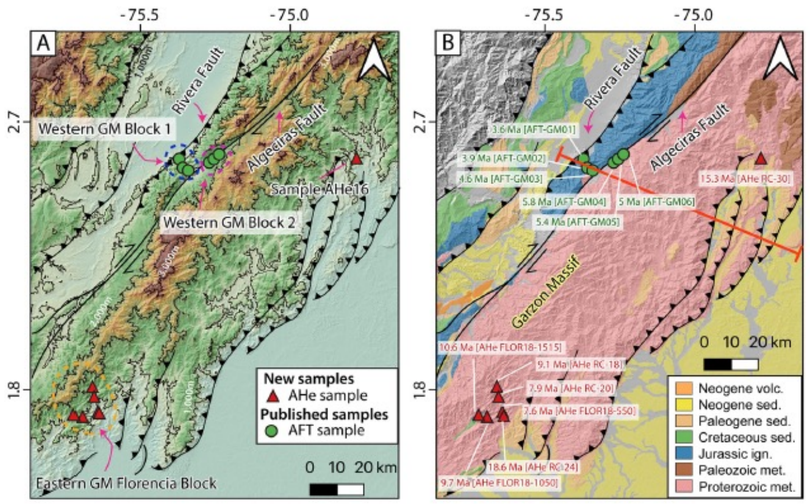


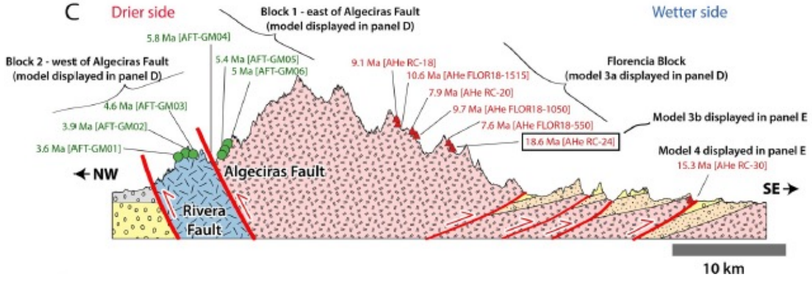
- Deformation within the western Guiana Shield is recorded during continental collision (with Oaxaquia ca. 1.2-0.9 Ga), manifested as Neoproterozoic impactogen structures and a Grenvillian granulite-grade metamorphic belt (Garzón-San Lucas-Santa Marta-Guajira).

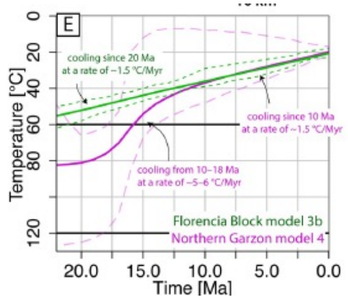
- The Arauca and Güejar impactogens configurated the early to late Paleozoic marine-rift-aulacogensthat were infilled by sediments of different ages, currently buried under a Meso-Cenozoic cover

- This structural configuration played a major role on the distribution of sedimentary facies during the Phanerozoic reflected in the basement maps that show prominent basement highs, compartimentalizing the Caguán-Putumayo and the Llanos basins, respectively

Exhumation during the Andean Orogeny

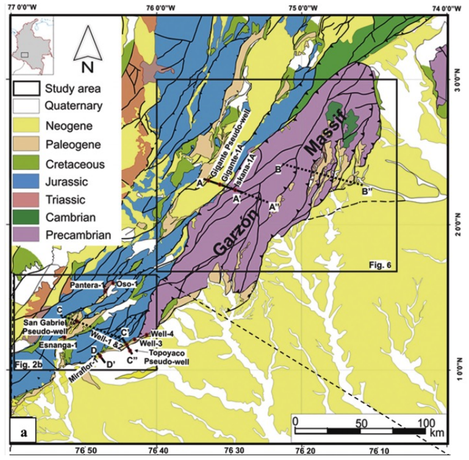




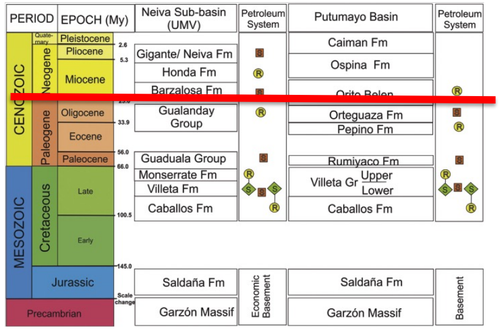


Availiable data indicates exhumation since the Miocene (15 Ma).

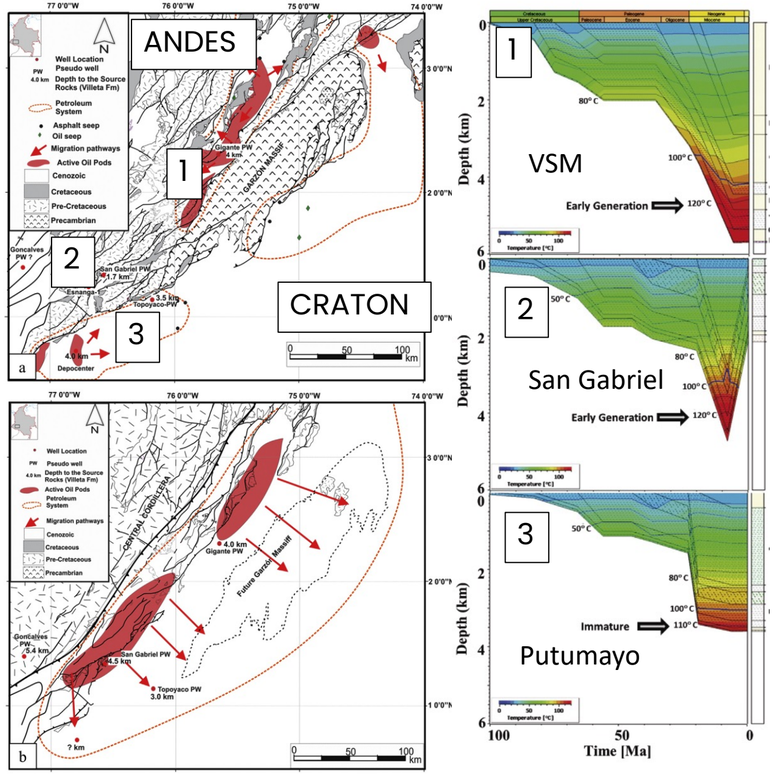
Perez-consuegra et al. (2021)
Saeid et al. (2017)
Burbery et al. (2019)

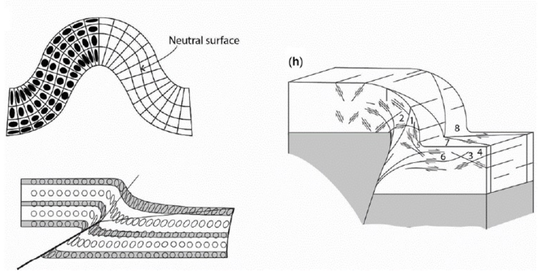


Estratigrafía y sistema petrolífero

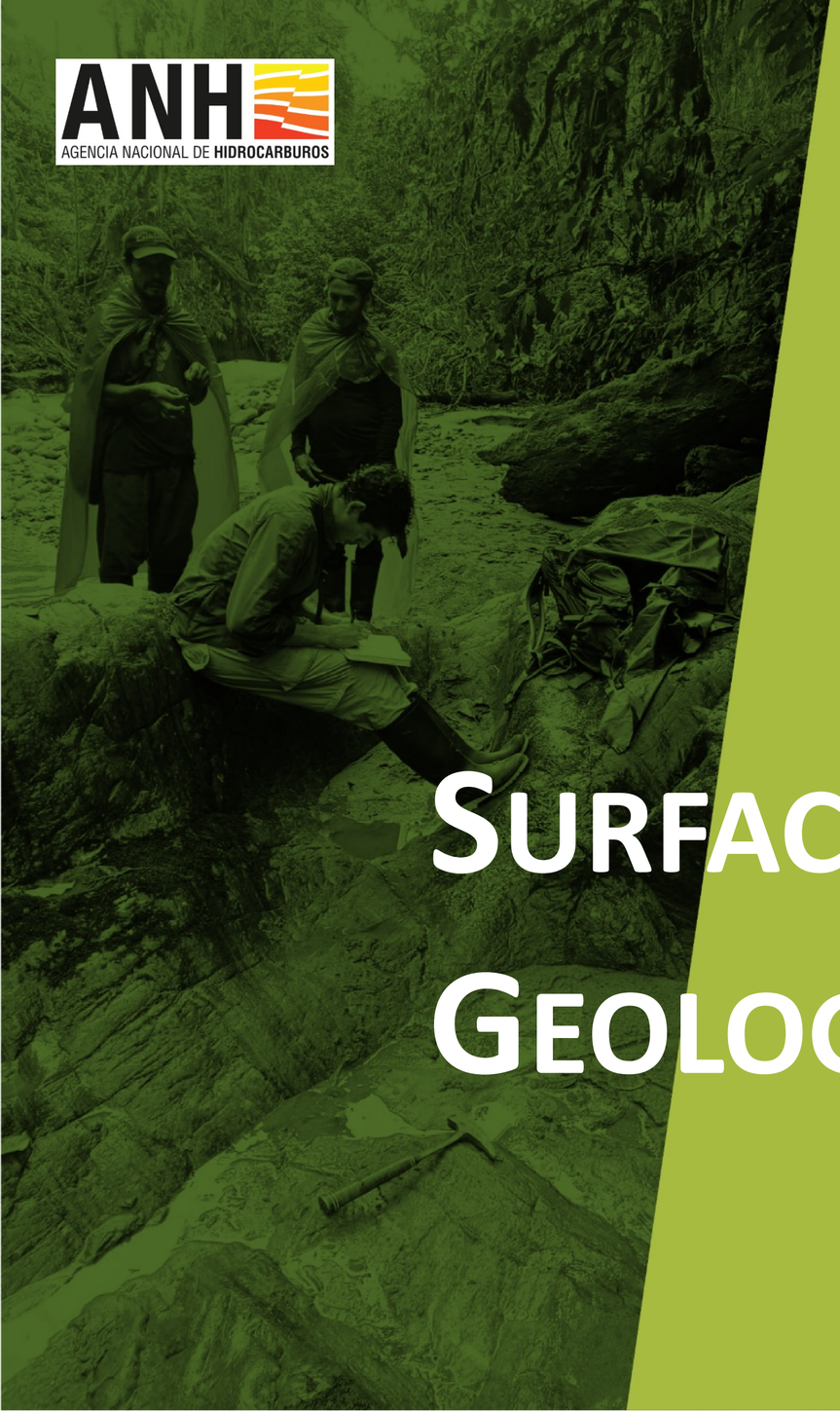


The Miocene exhumation hypothesis assumes migration from the UMV prior to the Miocene uplifting



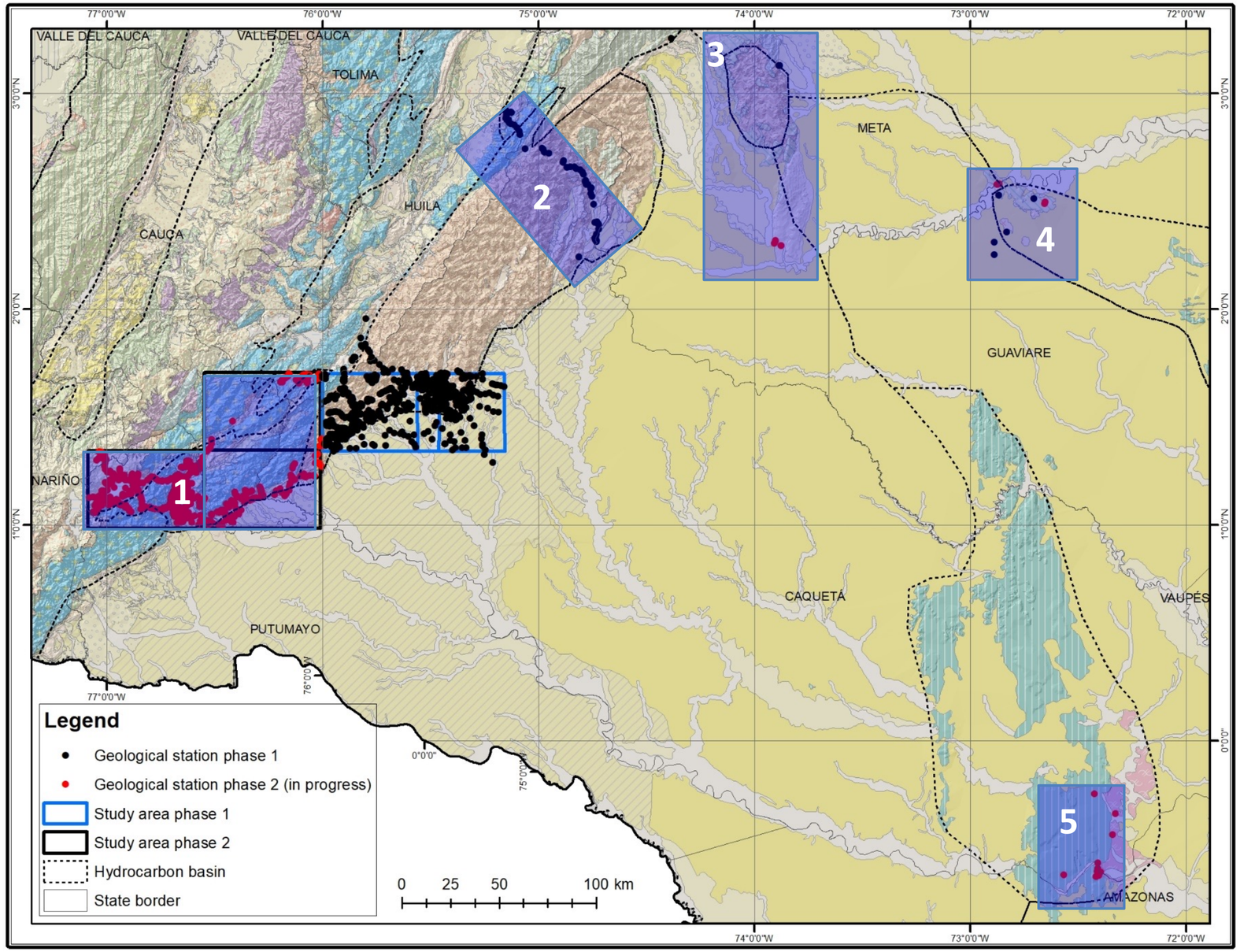


Thick-skin deformation"Tri-shear"



Surface Geology

Basement highs confining the Cagüán-Putumayo basin

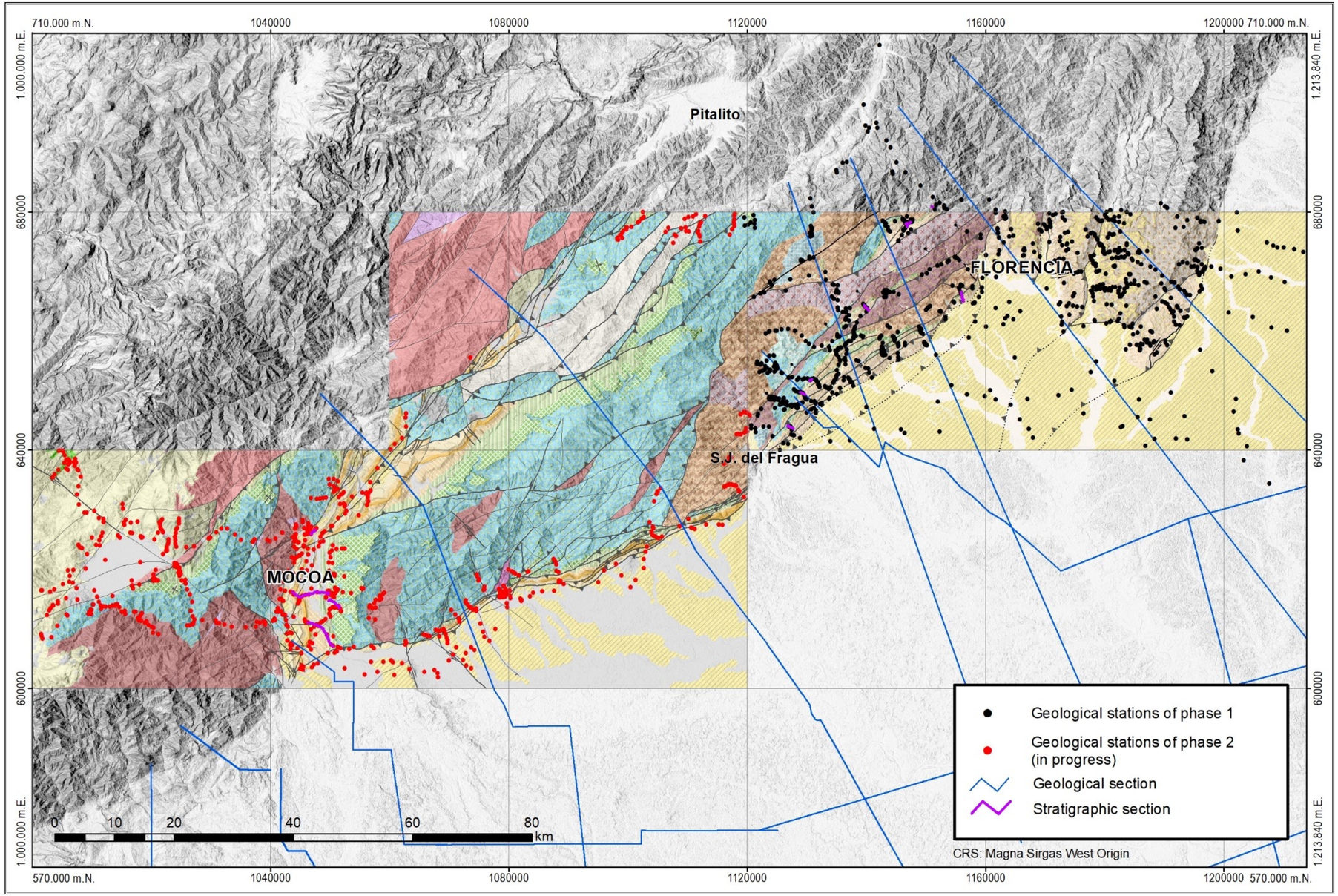


Field stations coverage performed during phases I & II of this project (**2021 black**, **2022 red**)

Sectors:

1) Garzón Massif
2) North Florencia High (Capella)
3) Macarena High
4) North Vaupés High (San José del Guaviare)
5) South Vaupés High (Araracuara)

The Garzón Massif and Florencia highs



Field mapping coverage reached over than 7000 km^2

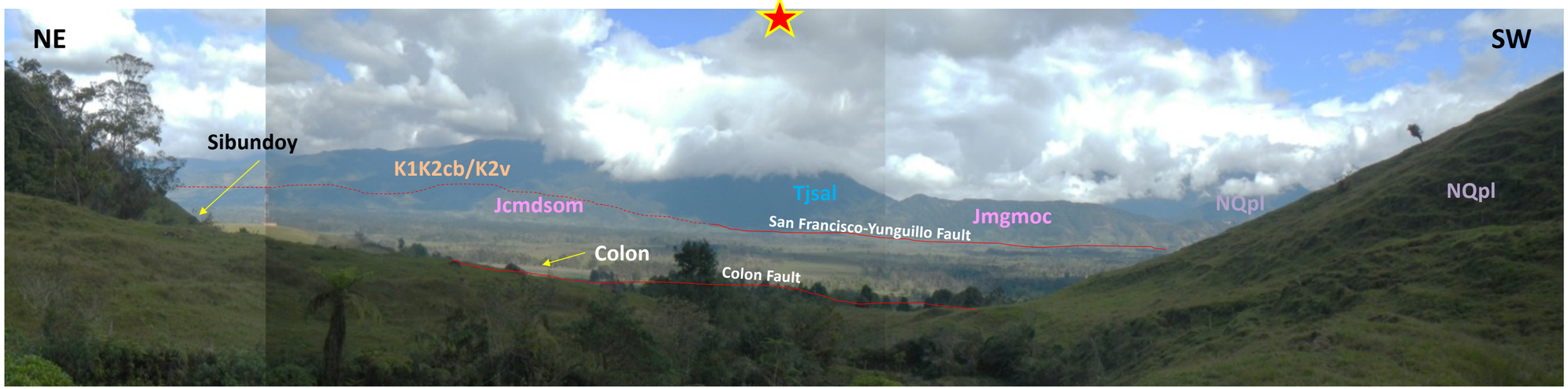
The foothils are dominated by crystalline tectonic slivers related to the advance of the deformation front

Basement rooted verticalized thrusts, and out of sequence frontal thrusts, control the easterly advance of the Andes

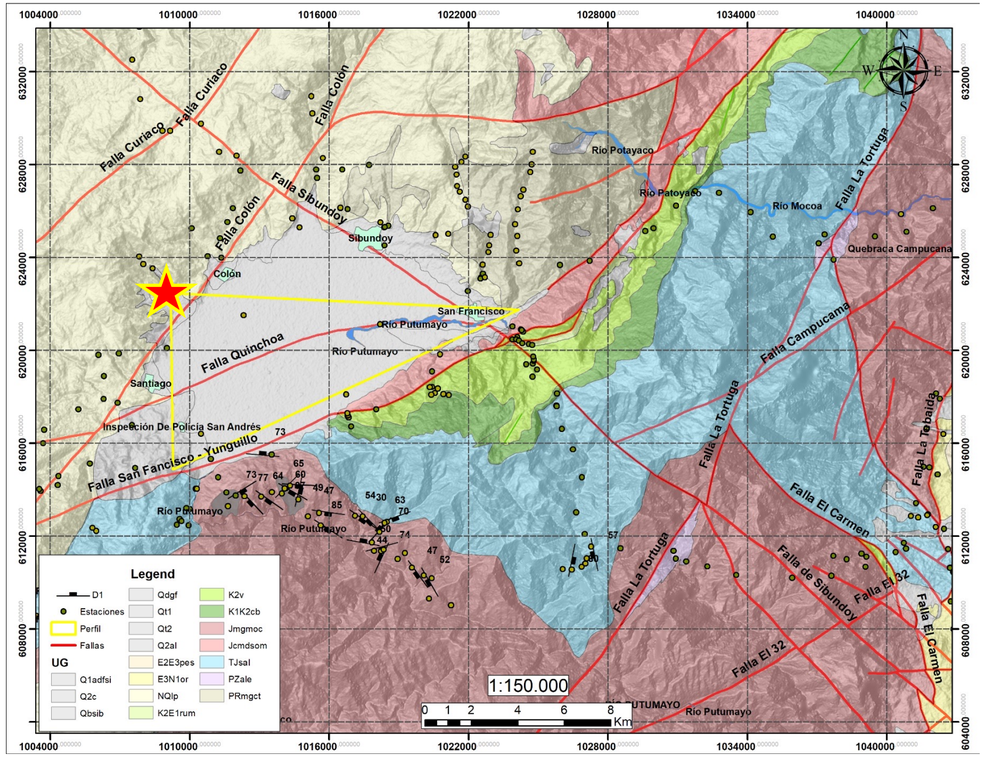
Late Miocene-Pliocene Strike-Slip tectonics

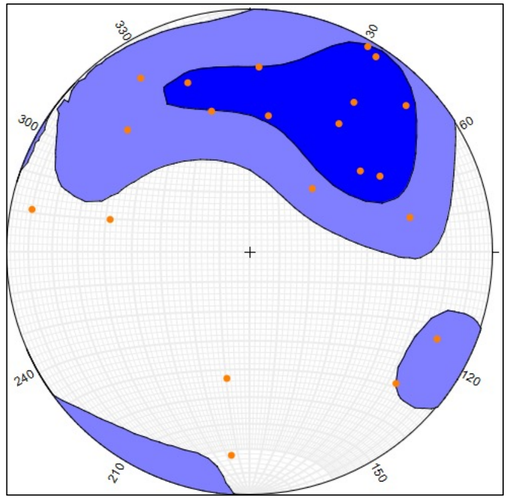
1) Borde Amazónico Fault
2) Algeciras Fault
3) San Francisco
4) Tebaida Fault
5) Las Hermosas Fault

Tectonically shaped landscape of the Sibundoy Valley

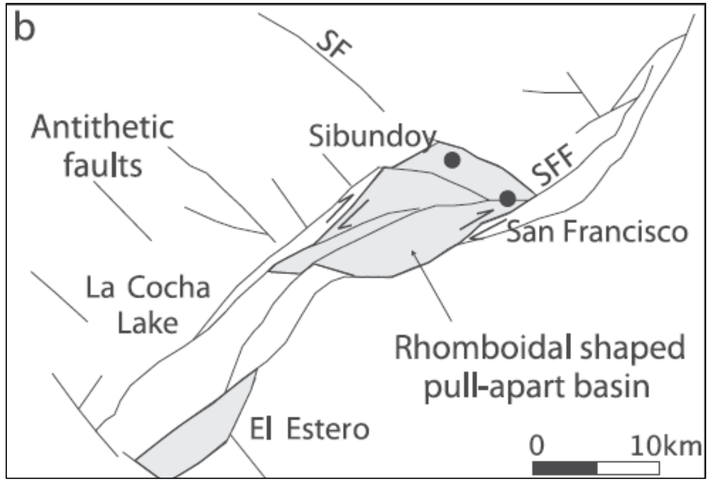


Velandia et al., 2005



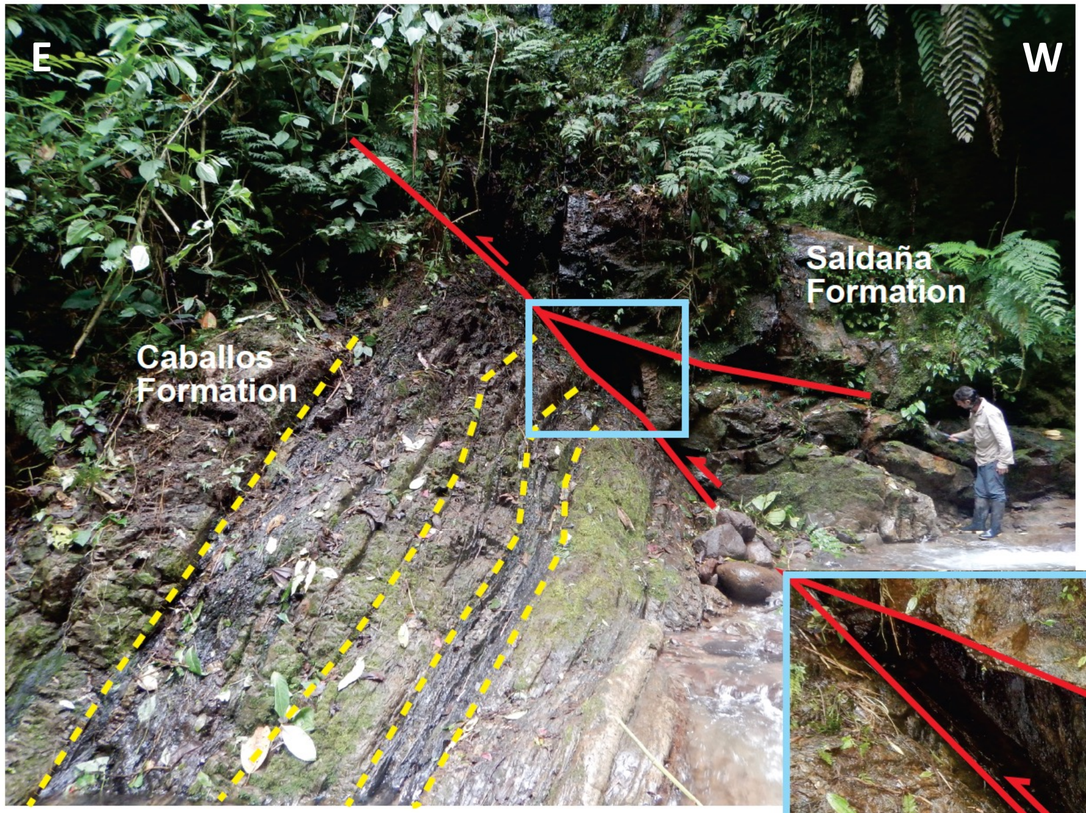


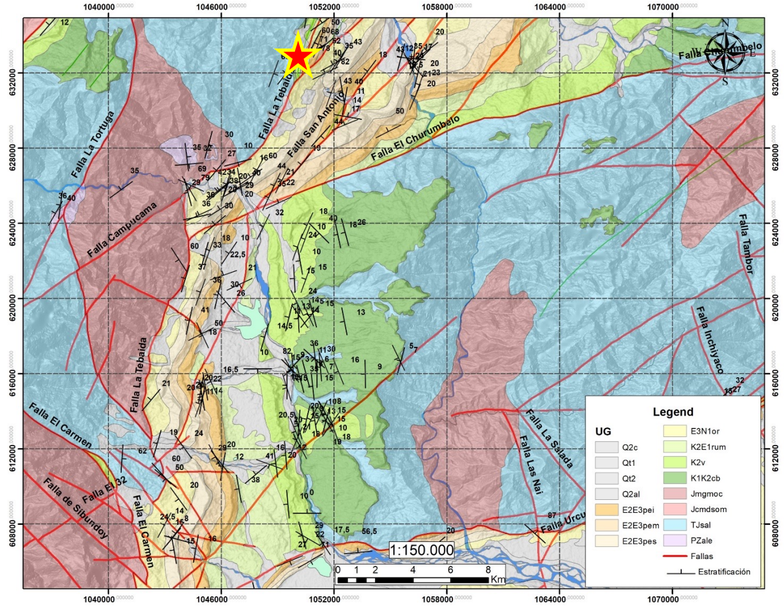
Joint planes D1 dipping towards SW with dip angles between 30° a 50°

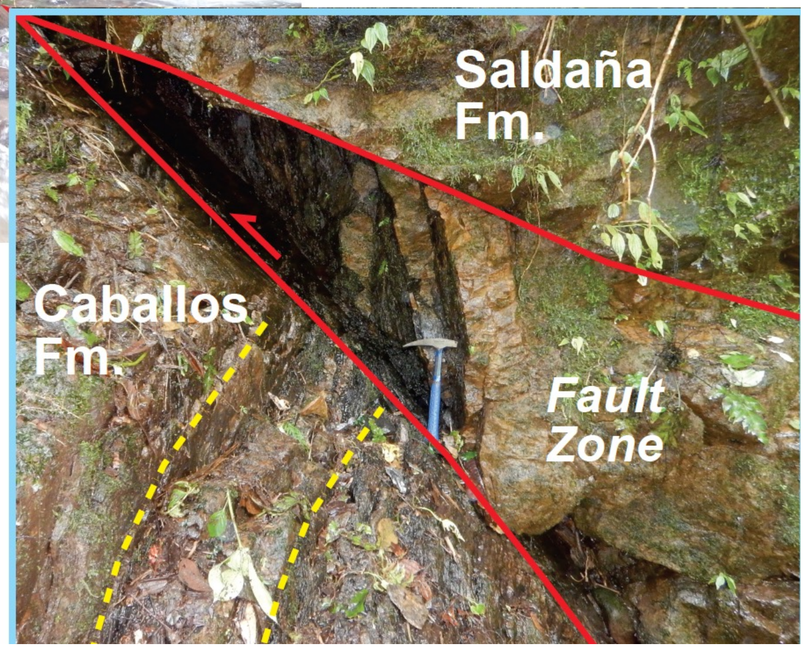


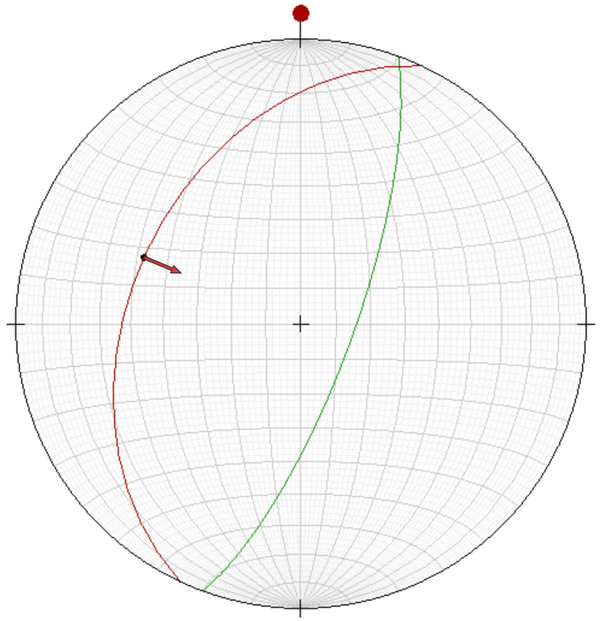
NE-SW oriented structures follow the Eastern Cordillera trend and accomaodate strain by thrusting and strike-slip

Algeciras Fault



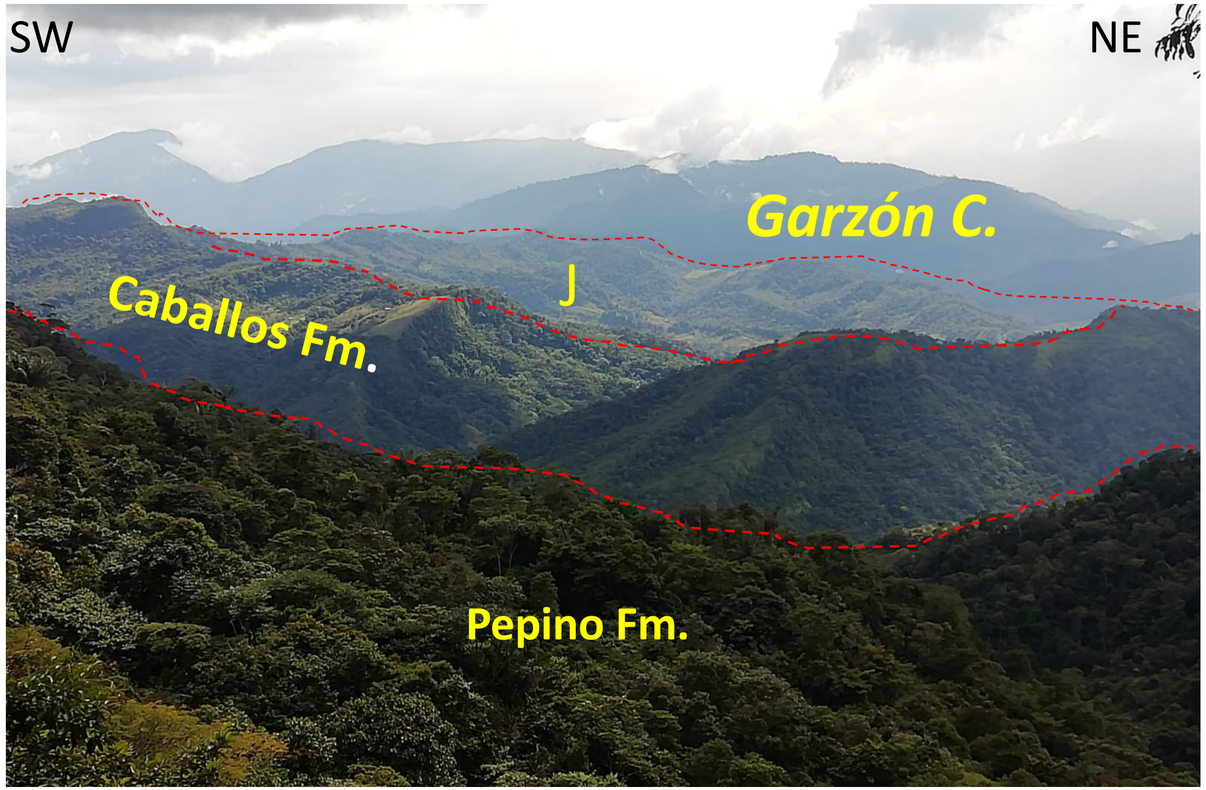






The Algeciras Fault
Is one of the most prominent structures, controlling the Cenozoic uplift of the Eastern Cordillera

The Garzón Massif and its sedimentary cover



- **Four regional unconformities (Jurassic, Aptian, Maastrichtian, Middle-Eocene)**
- Verticalized faults repeat the sedimentary successions and involve the crystalline basement (**Thick-skin**)
- Calcareous rocks increase in thickness towards the SW
- In general, Cretaceous sedimentary units increase in thickness towards the SW, far from the Florencia high

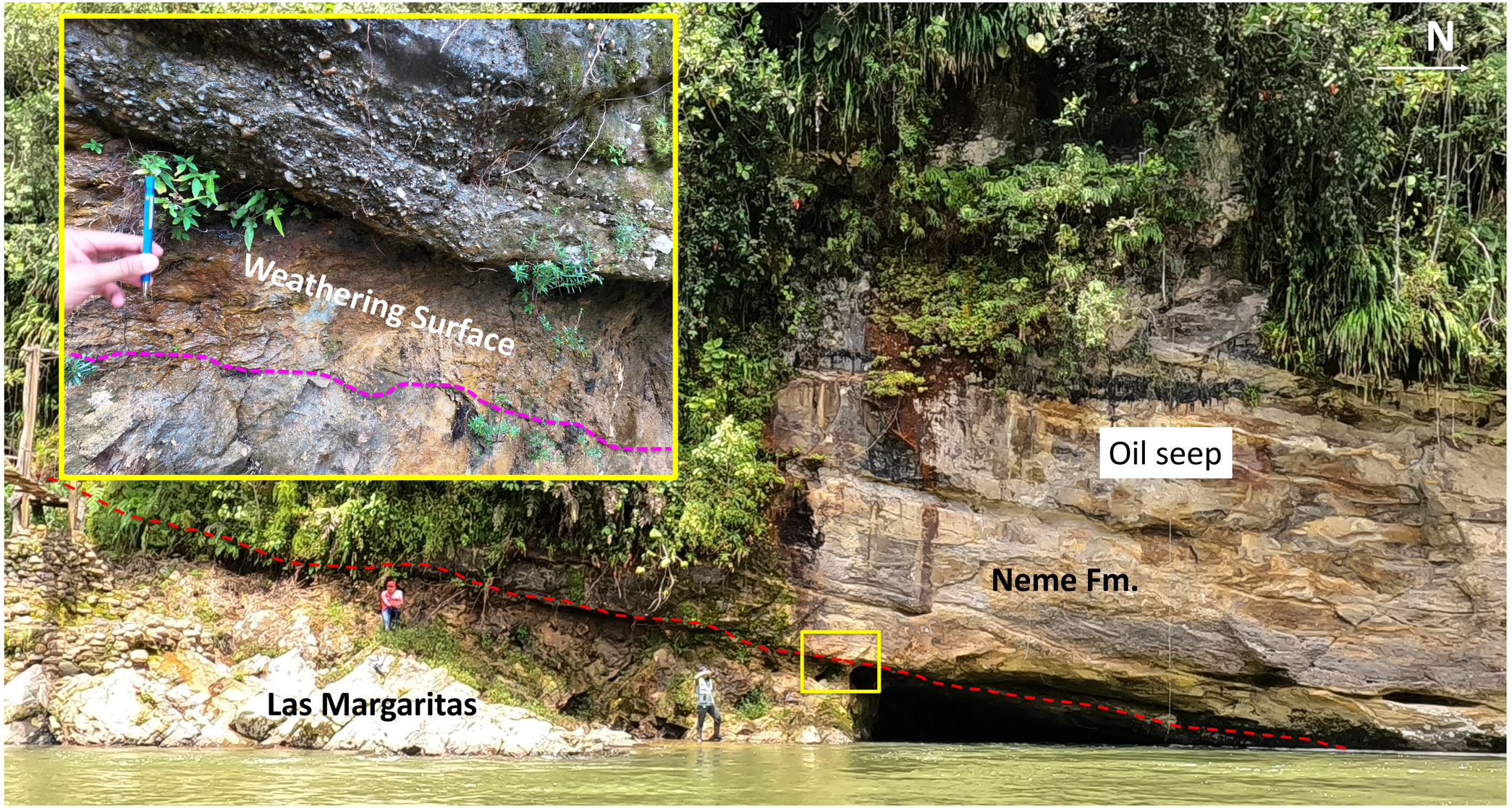
Caballos Fm. Basal Unconformity (Aptian)

Erosive contact between tuffs of the Saldaña Fm. And the Caballos Fm. Aguascalientes Creek, (Morelia).

Unconformity between the Caballos Fm. And the Garzón Complex. La Tortuga Creek , San Carlos (Florencia).

Evidences of exhumation of the Garzón Masiff and Jurassic arc during the Cretaceous.

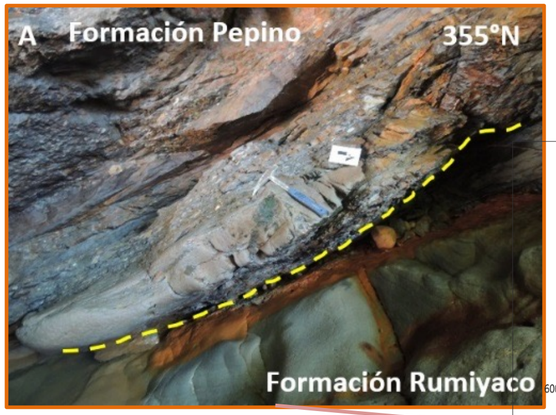
Unconformity Neme Fm. (Paleocene) –Proterozoic Basement



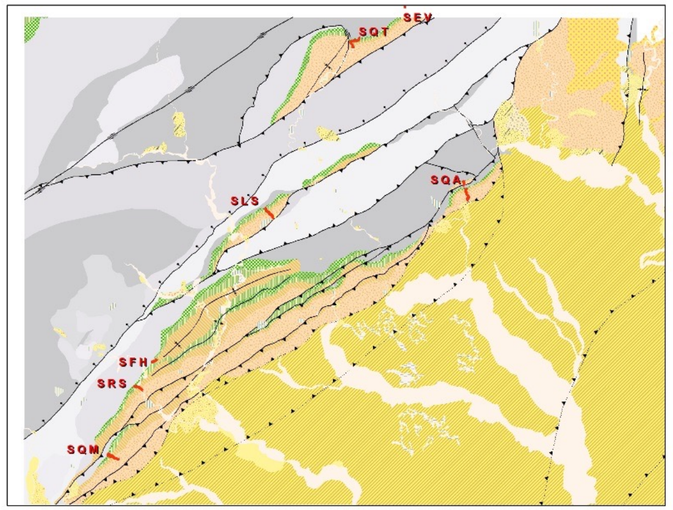
Unconformity between the Neme Fm. And the Garzón Complex at the San Pedro river , Victoria Baja(Florencia)

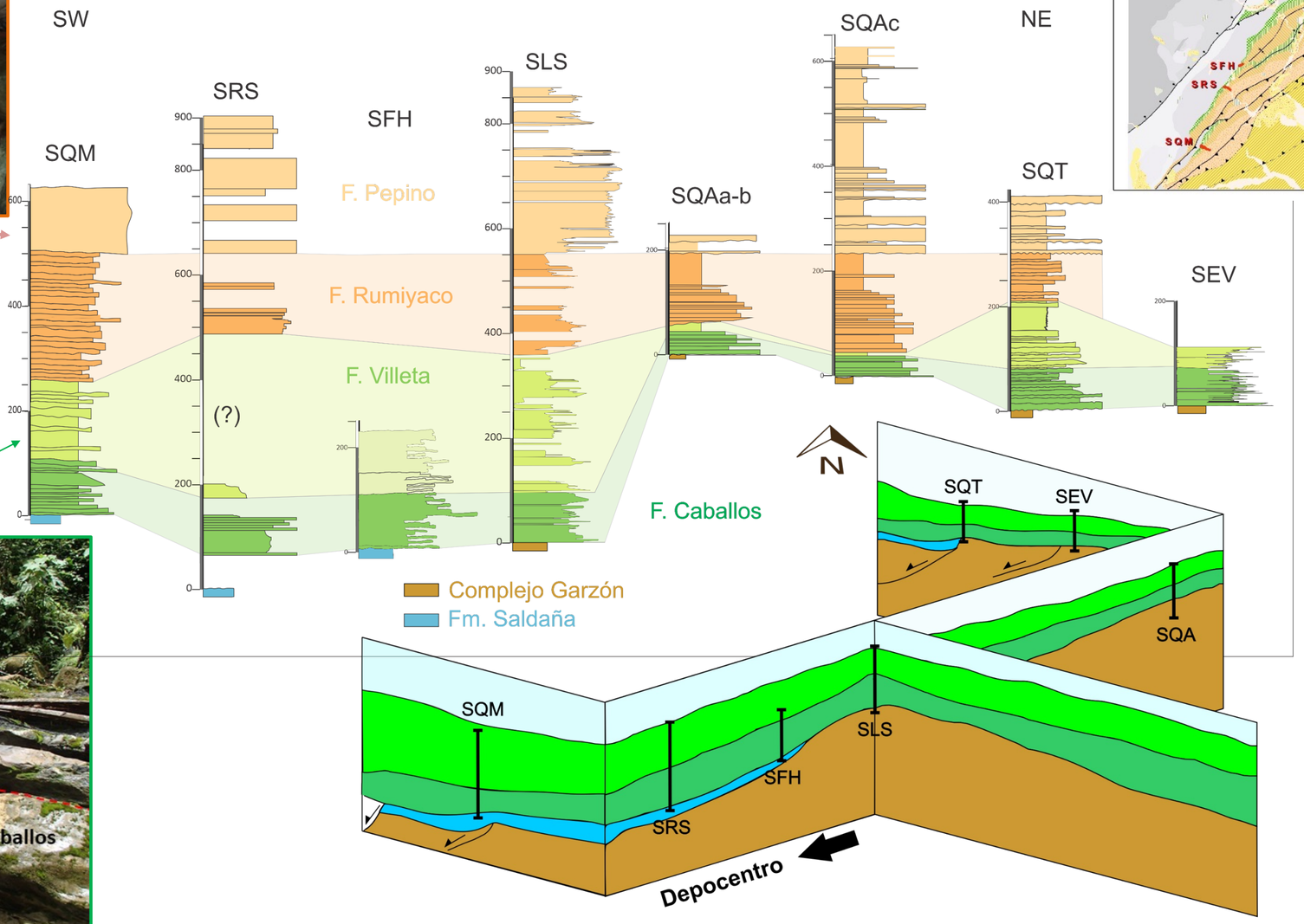
evidencie of Garzón Massif exhumation during the Paleocene

Stratigraphic Correlation Florencia Foothills



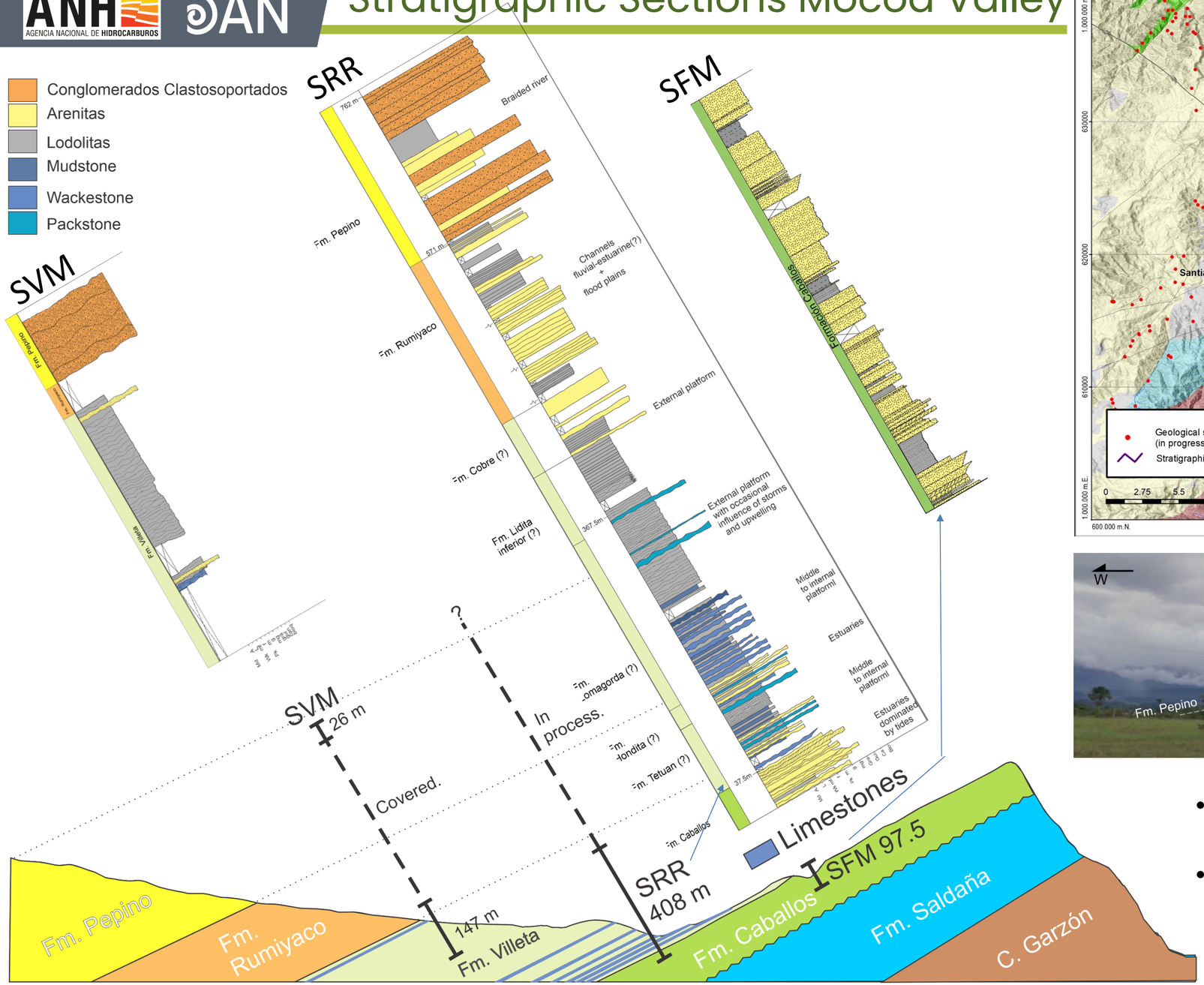
Datum:
Contact between the Rumiyaco and Pepino formations

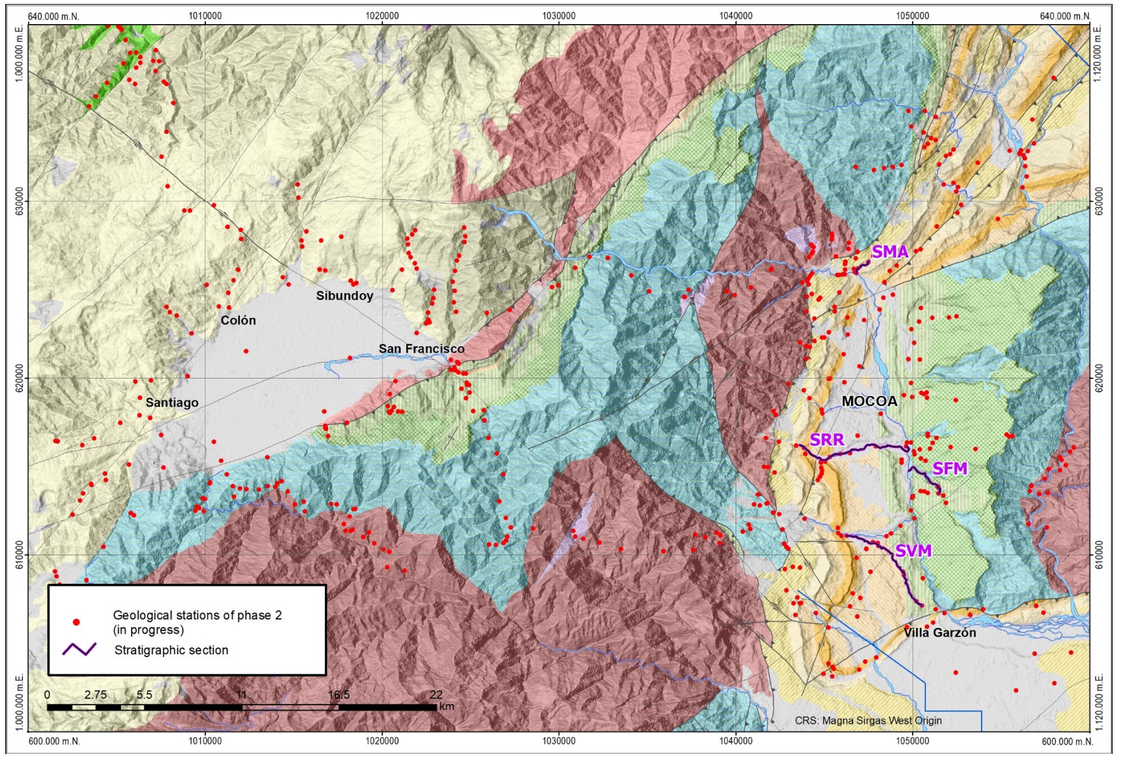


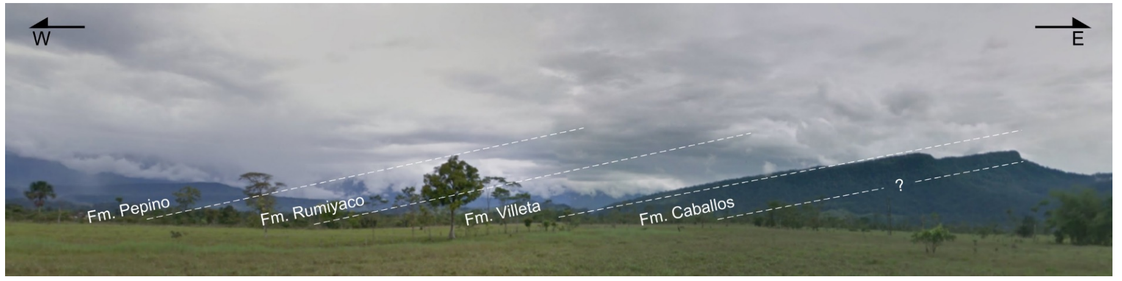


Stratigraphic section	Samples	(m.)
SQM	48	741
SRS	10	853.5
SFH	8	232.5
SLS	45	858
SQA (a)	10	186
SQA (b)	7	55.5
SQA (c)	7	625.5
SQT	21	405
SEV	22	109.5
TOTAL	178	4066.5

Stratigraphic Sections Mocoa Valley

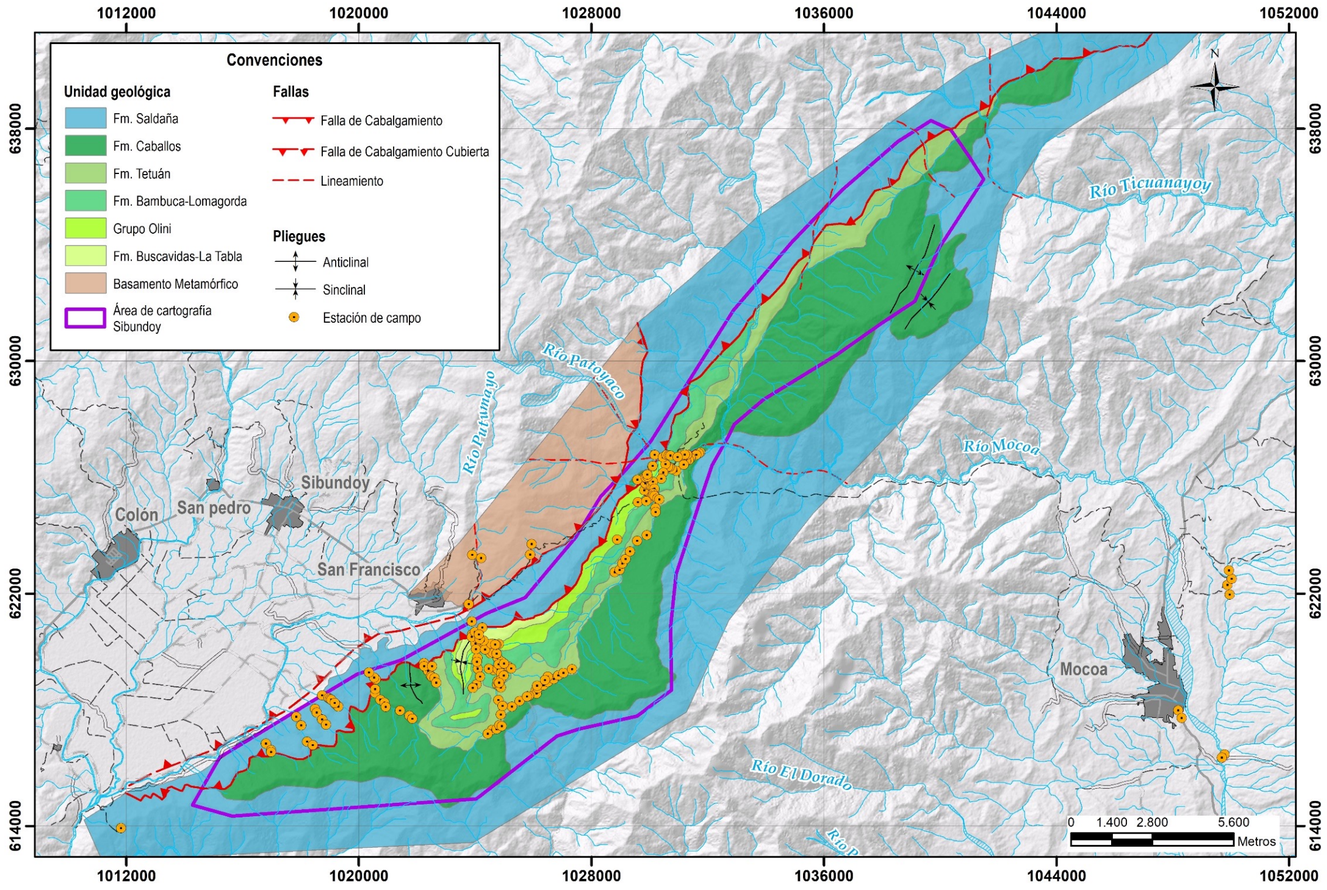


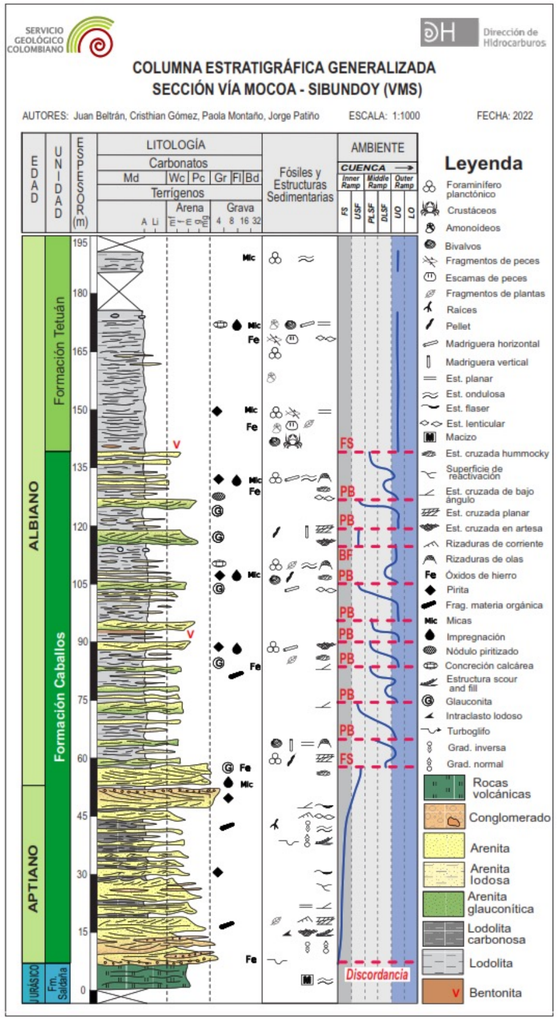


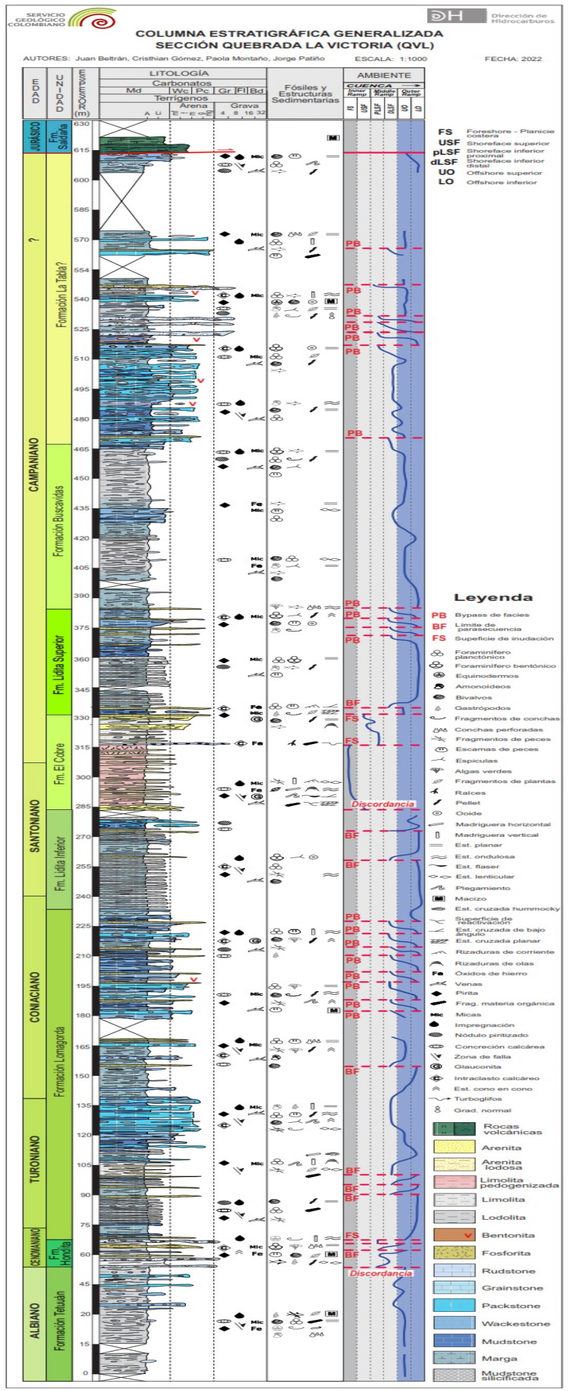


- The most representative section corresponds to the Rumiyaco River section **SRR**
- The Rumiyaco Fm. unconformably overlies the Sandstones of the Cobre Fm. (Campanian-Paleocene hiatus)

Stratigraphic Sections Sibundoy Valley

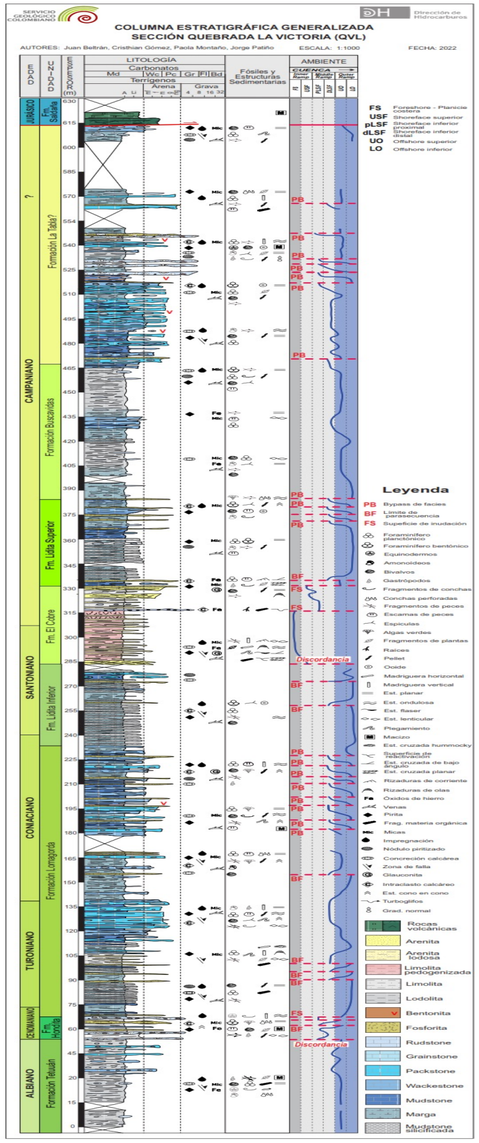


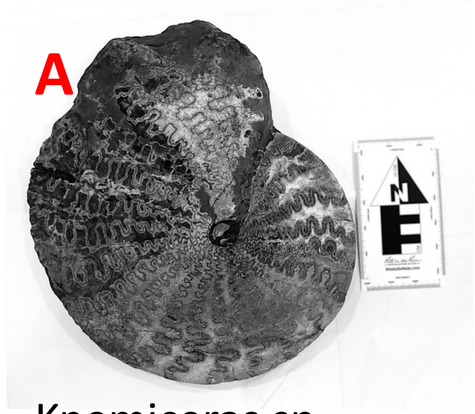




- Two representative sections in the road Mocoa-Sibundoy and La Victoria Creek showed the complete Cretaceous sequence, including the Oliní Groupp
- **In these section the Paleocene unconformity of the Rumiyaco Fm. is absent**
- **Ammonite fauna is indistinguishable from the UMV sections**

Stratigraphic Sections Sibundoy & Mocoa Valleys





Knemiceras sp.

Acanthoceras?

Fm. Pepino

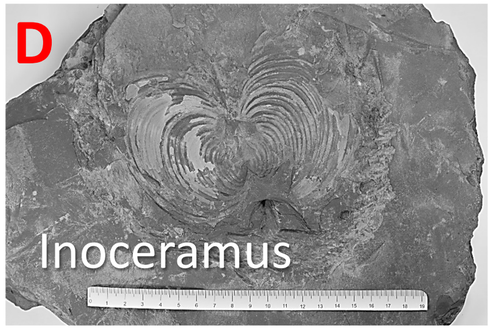
Fm. Rumiyaco

Acanthoceras

Xylopal

Fm. Cobre (?)

Fm. Lidita inferior (?)

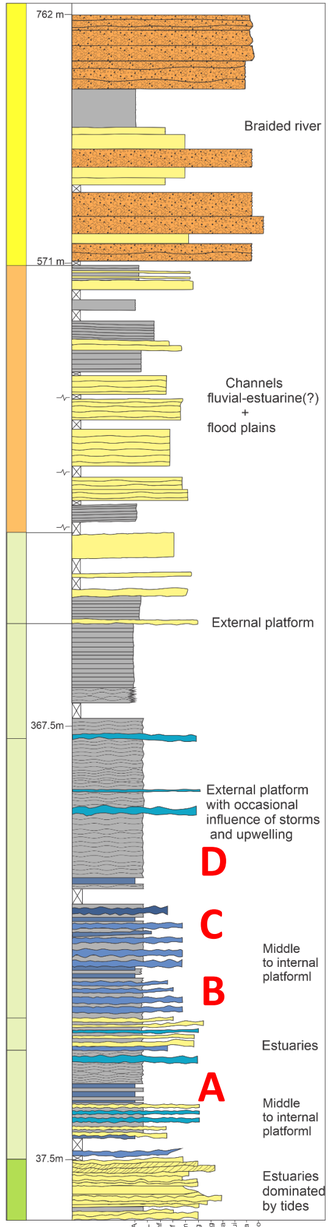


Fm. Lomagorda (?)

Fm. Hondita (?)

Fm. Tetuan (?)

Fm. Caballos

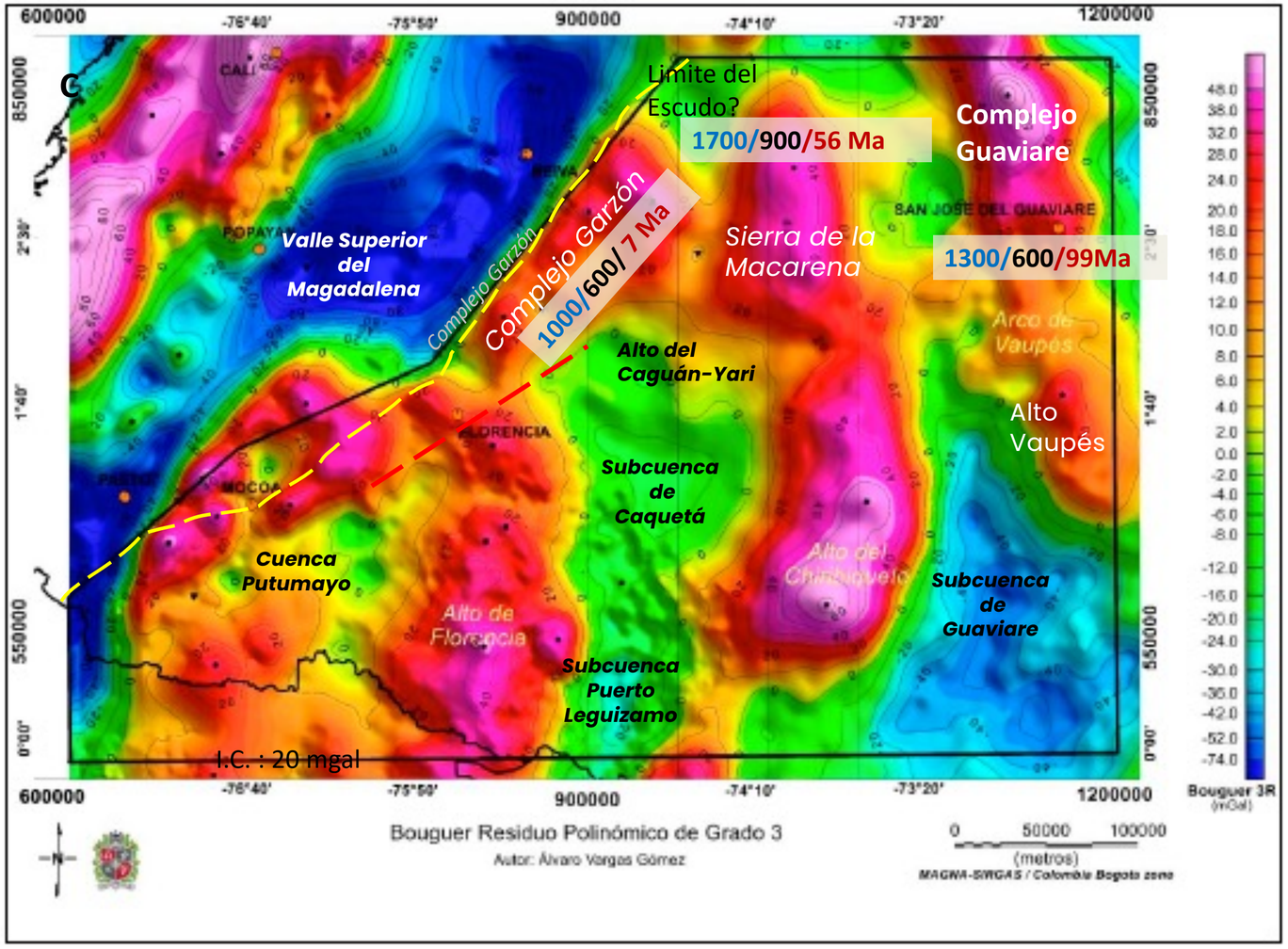


The ammonite fauna in the Sibundoy and Mocoa Valley can be correlated with the fauna of the UMV, **indicating a marine connection during the late Aptian to the early Coniacian between the Putumayo and UMV depocenters**

SEISMIC INTERPRETATION

A

Regional subsurface approach



Upper Magdalena Valley Basin

Eastern Cordillera Range

Putumayo Basin

Garzón Complex
Florencia High–Caquetá High- Caguán High
Aquarico High(Ec)

Cagüán-Yarí Sub basin, Caquetá Sub basin–
Puerto Leguizamo Sub basin

Serranía de la Macarena
Yarí High, Chiribiquete High
Iquitos High(Ec)

Guaviare Sub basin

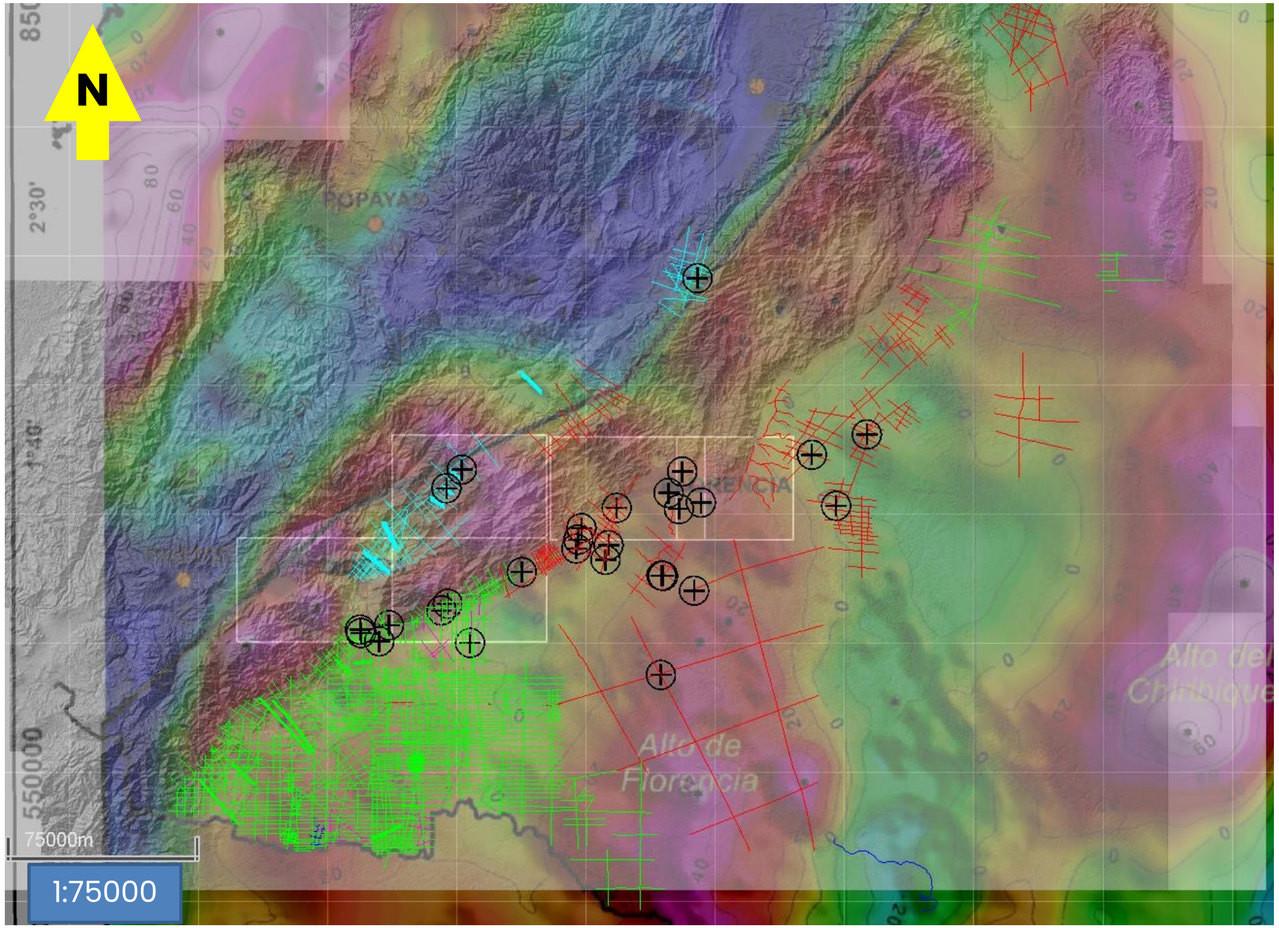
Guaviare Complex
Viento Melón High
Vaupés High

Red: Highs
Blue: lows

Crystallization and Exhumation Data of Basament highs plotted on the gravimetric map. The map shows the compartmentalization of the basins. Data from Petro-Thermochronology (AFT, AHe, U-Pb)

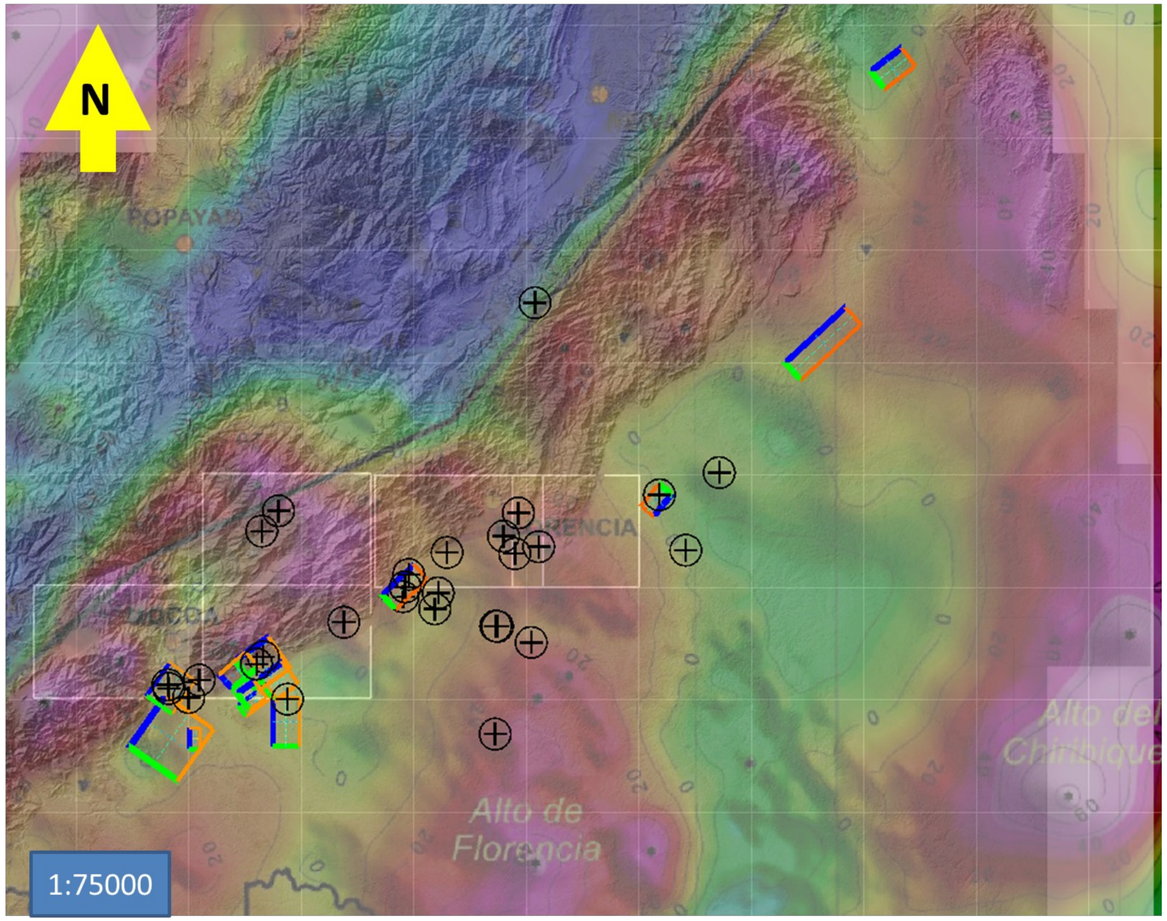
Available information (wells and seismic)

2D Lines + Wells



- Phase I
- Phase II Caguán Putumayo
- Phase II VSM
- Wells

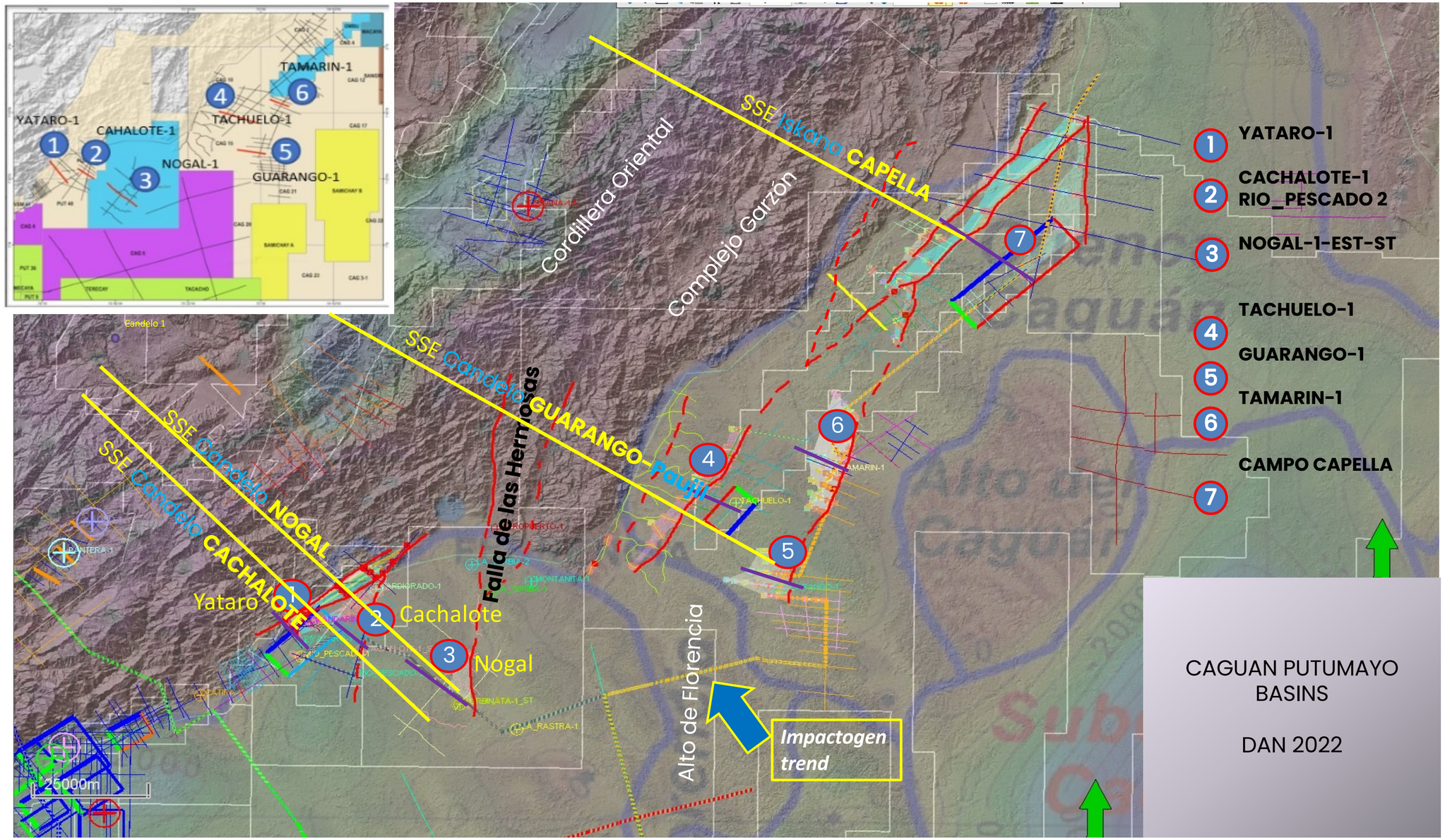
3D Volumes



SEISMIC AVAILABLE PER BASIN (SEGY)		
Basin	**FASE I**	**FASE II**
UMV	14 (2D)	93 (2D)
CAG	167 (2D) + 4 (3D)	24 (2D)
PUT	15 (2D) + 1 (3D)	541 + 10 (3D)
Load In Petrel	196 (2D) + 5 (3D)	658 + 10 (3D)

WELL INFORMATION – BIP (Well)		
STATUS	**FASE I: 2021**	**FASE II: 2022**
Requested	634	218
Received	625	184
Checked	149	89
Load in Petrel	22	45

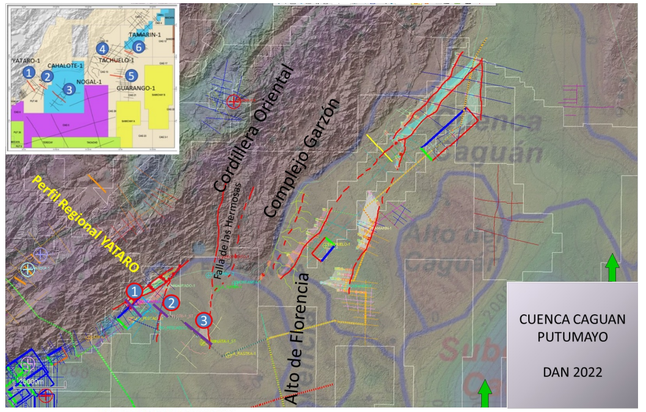
Seismic section with structural interpretation (SSE)



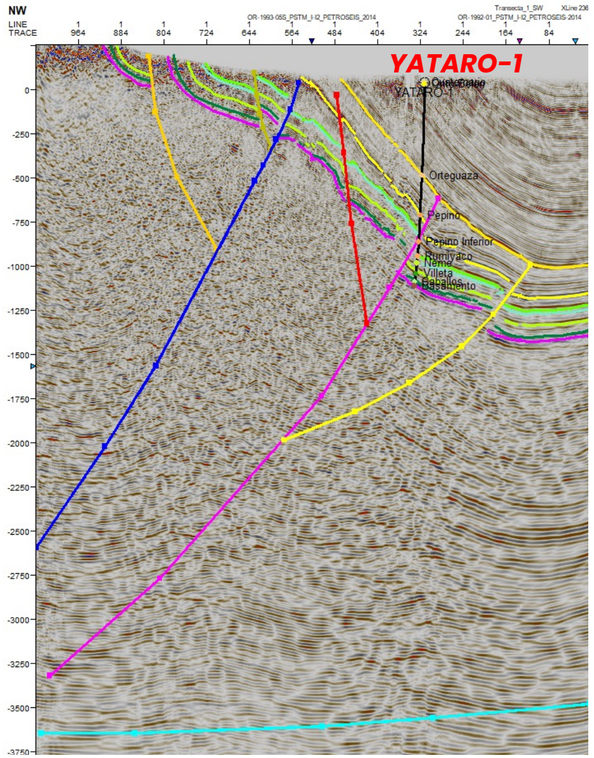
Yataro seismic-structural section

Interpretation of the structural style in the Caguán-Putumayo Basin (Phase I), characterized by reverse faults associated with a detachment fault at 3.0 sec (TWT)

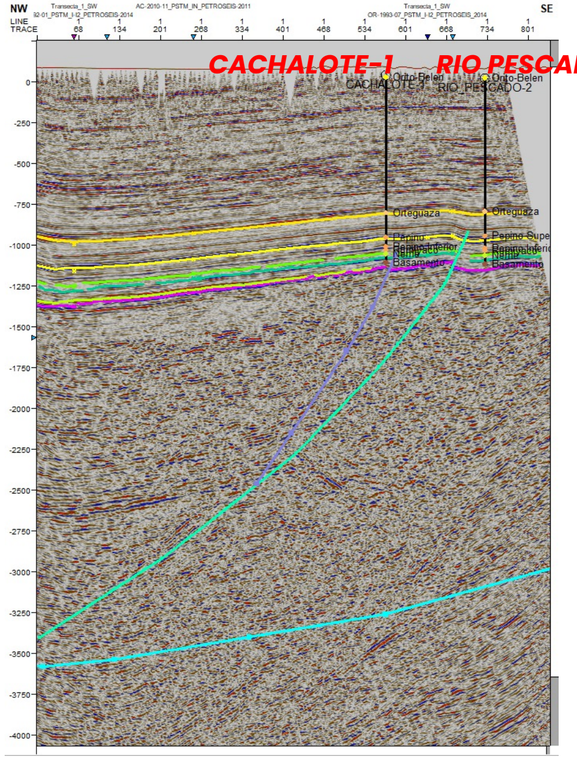
The length of the deformation from the foothills to the Nogal EST -1 ST well is 40 km, and the distance to the Florencia Paleo-high is 80 km.



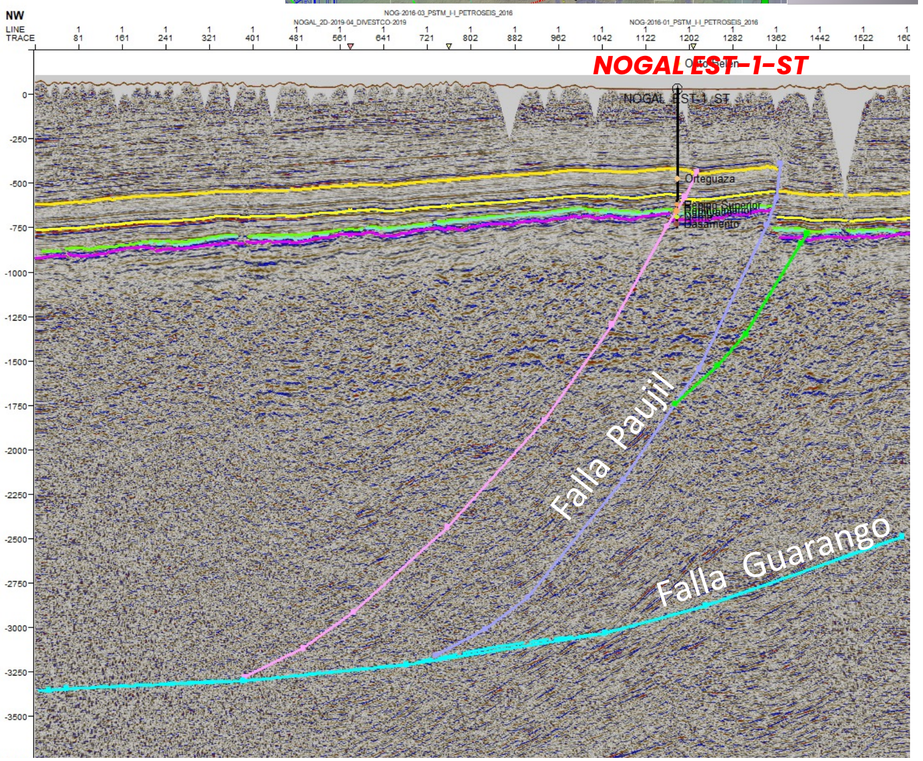
1



2



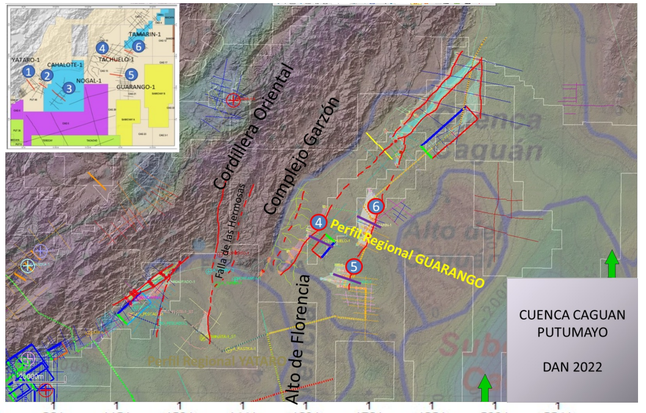
3



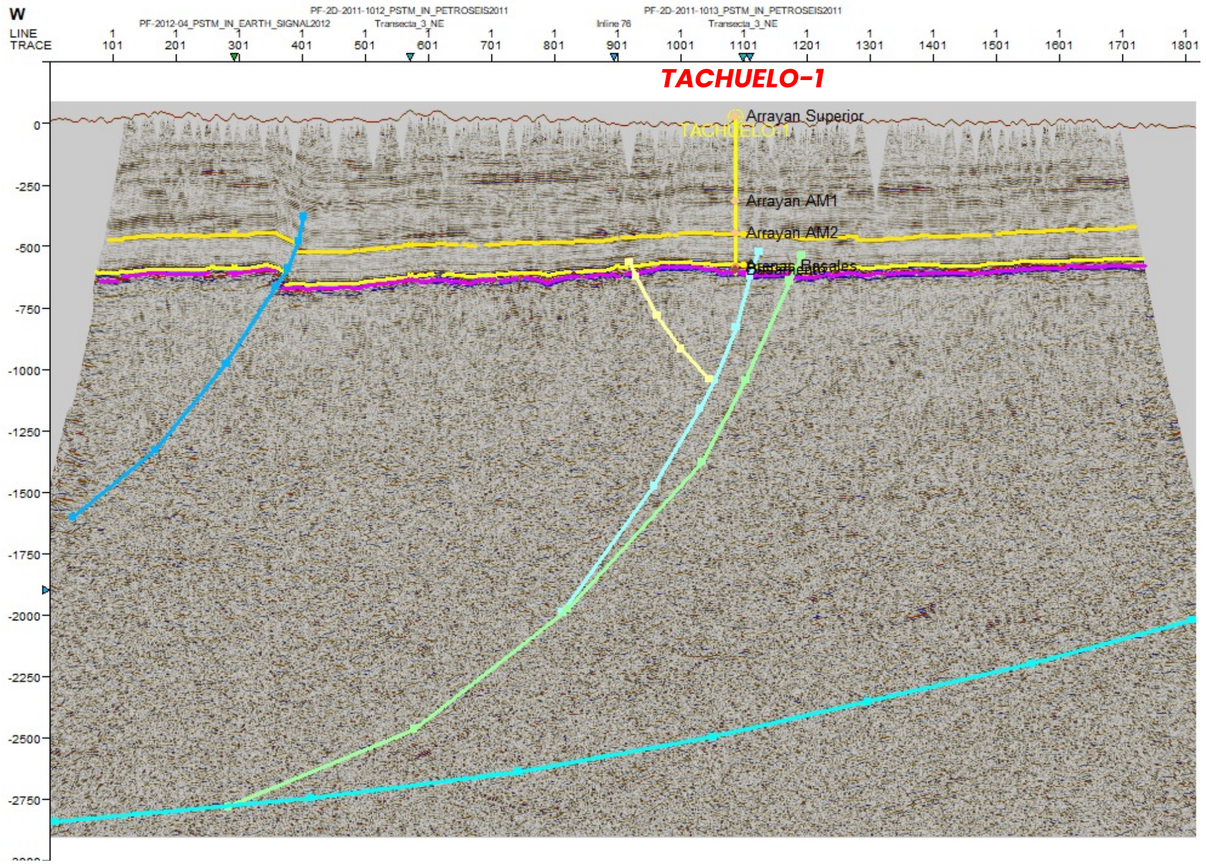
Guarango seismic-structural section

The detachment fault is generated from the deformation of the Cordillera Oriental foothills in the West.

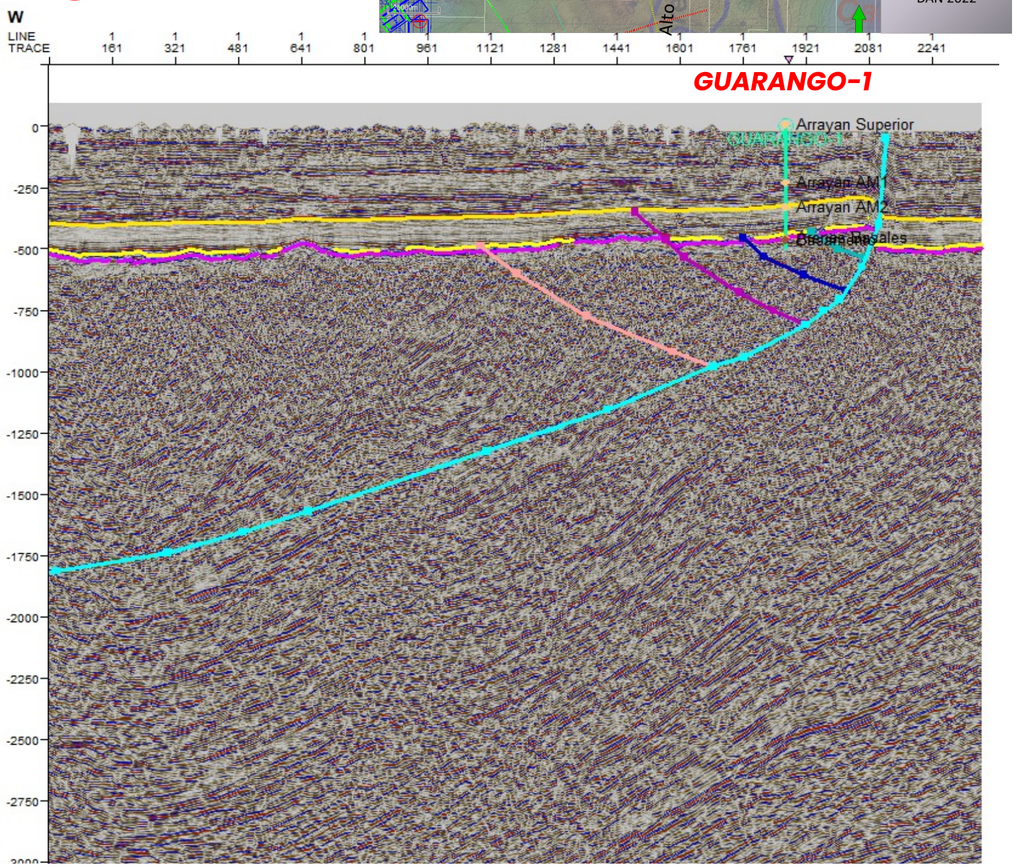
The length of the deformation is 40 km from the Cordillera Oriental foothills to the Caguán Paleo High.



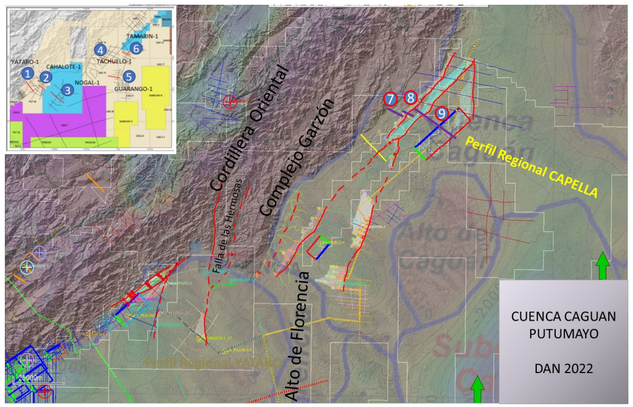
4

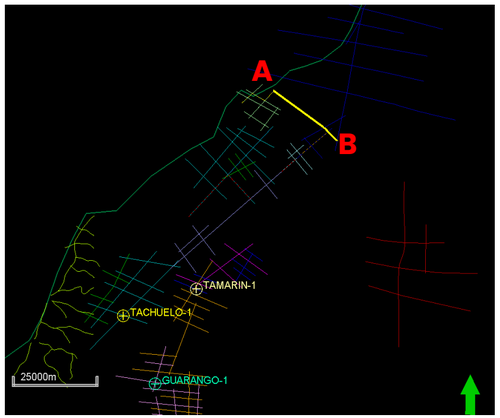


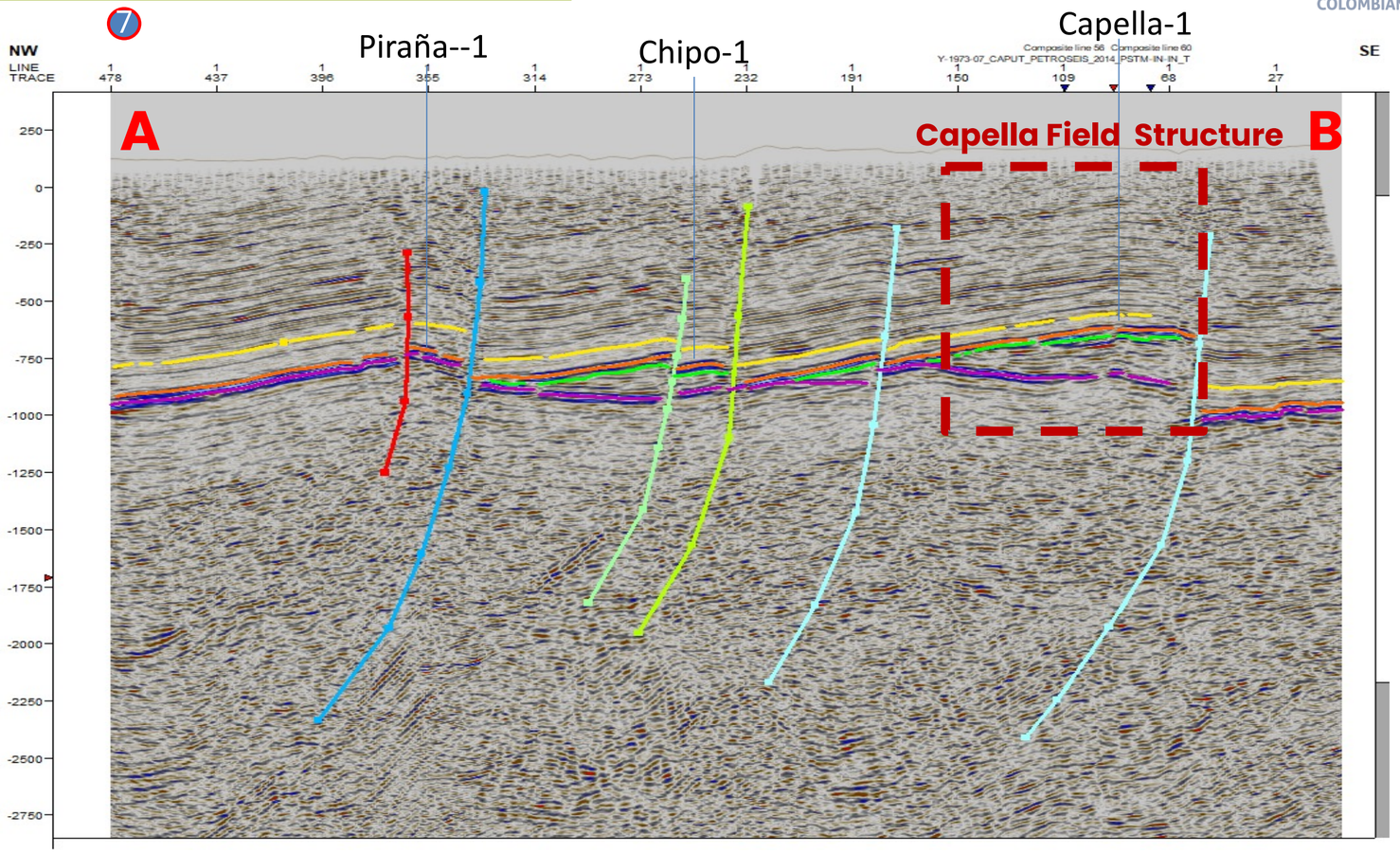
5



Capella seismic-structural section

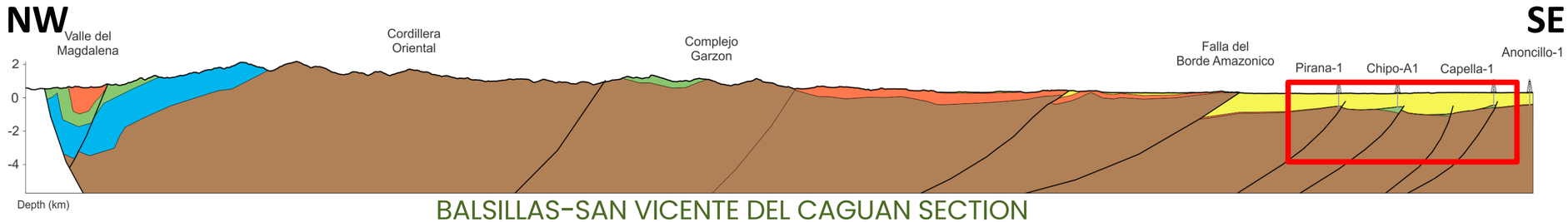






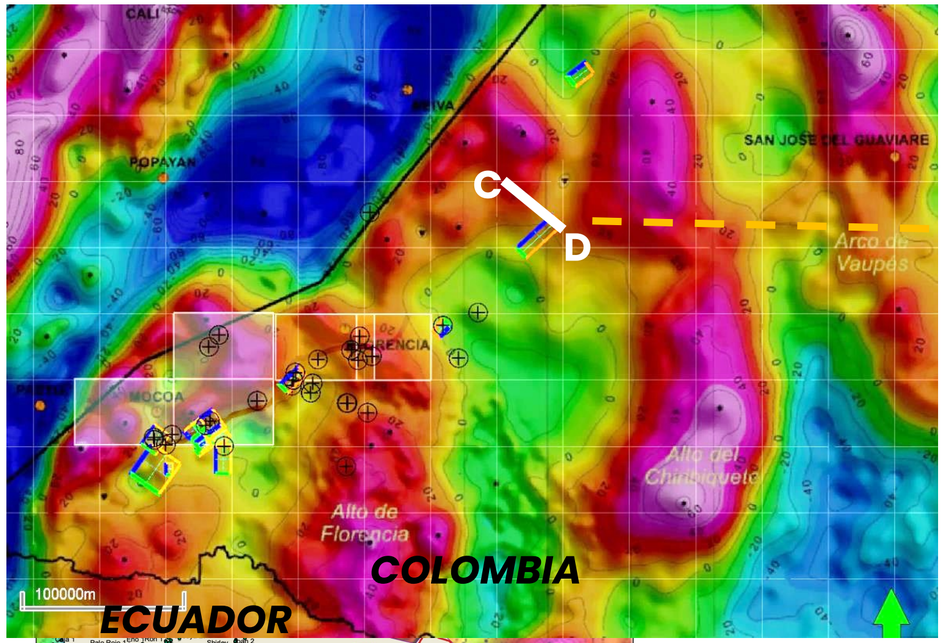
- Orteguaza Fm. / Arrayán AM2
- Pepino Fm. / Mirador Fm.
- Pre-Cretaceous rocks?
- Basament

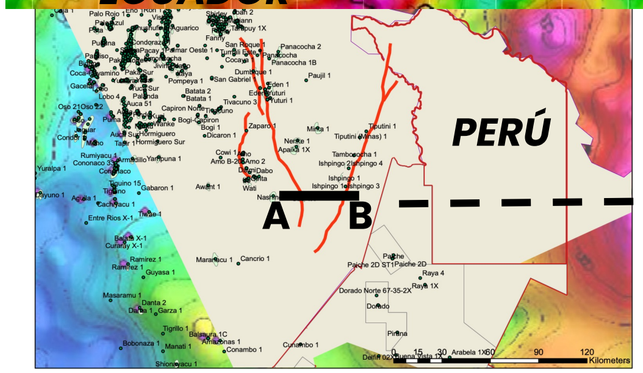
Structural Style: Inverted Rift.

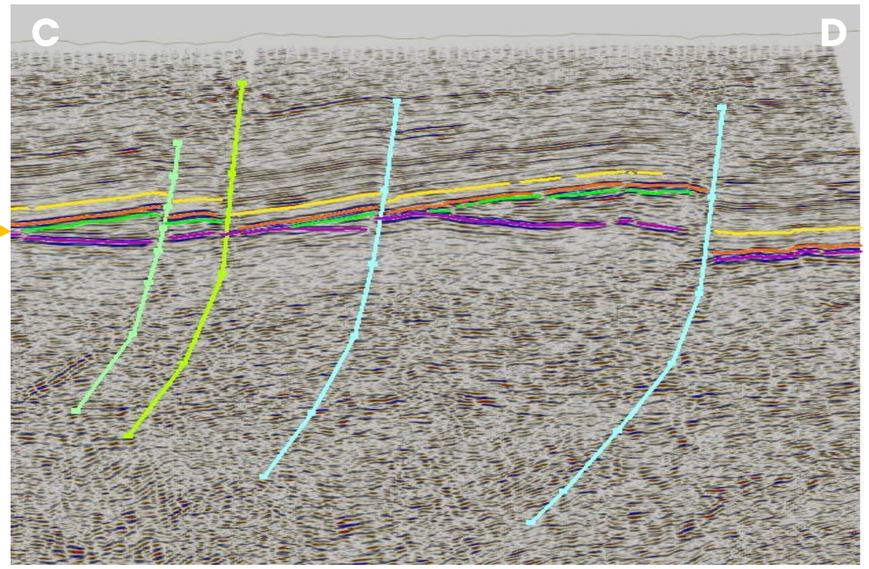


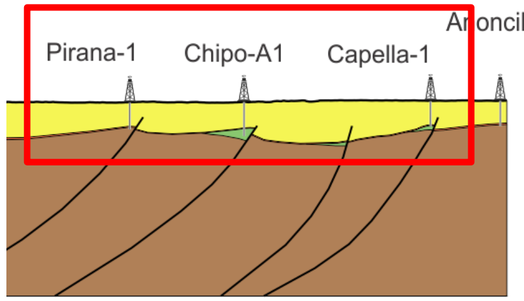
BALSILLAS-SAN VICENTE DEL CAGUAN SECTION

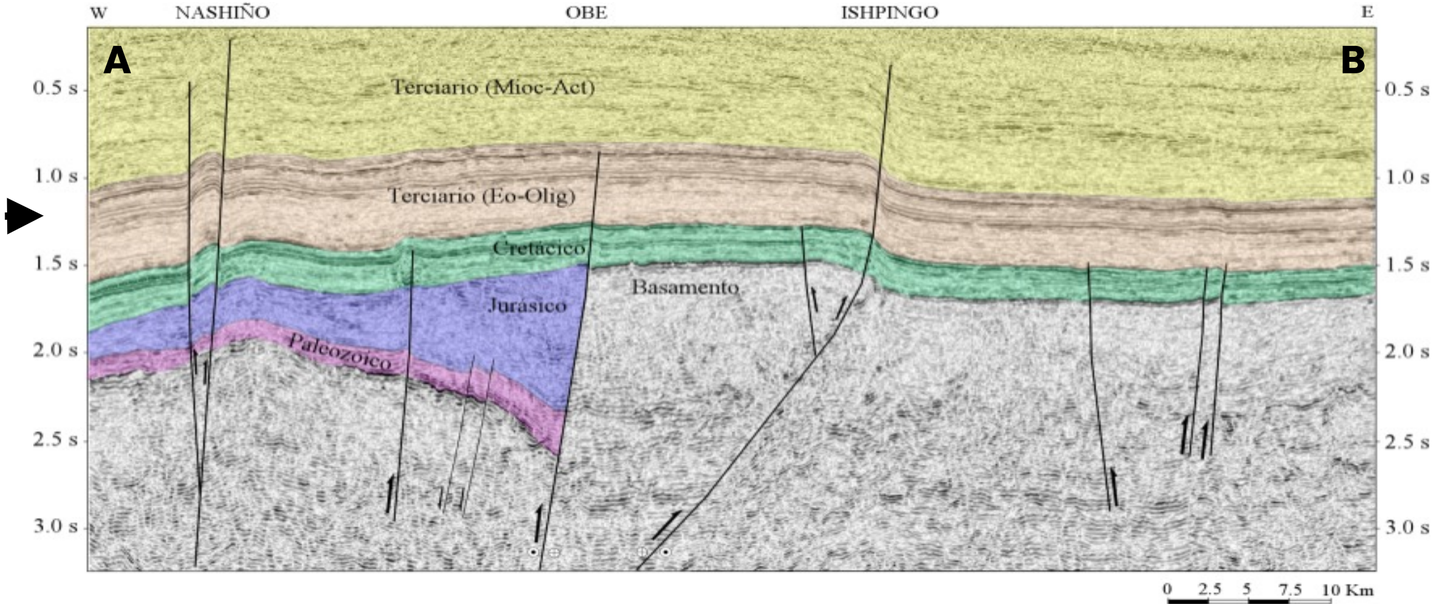
Capella seismic-structural section





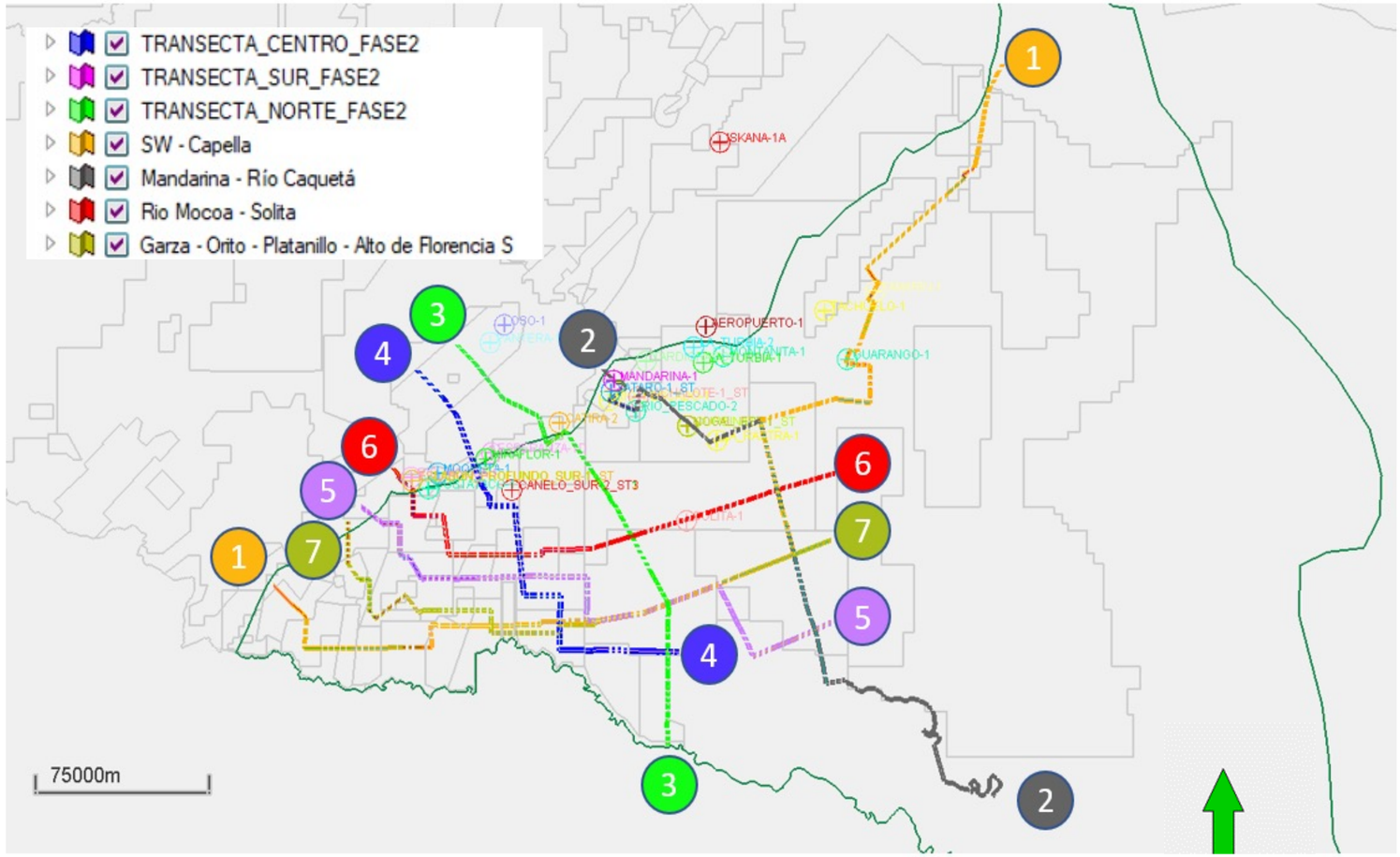






To the north and south of the Caquetá depocenter, there are the Capella field and the complex of fields ITT respectively, Together presenting a similar structural pattern of inverted semi-graben.

Map of regional transects phase II



An advance of the interpretation of the transects **1, 3 y 6** is showed later

Defined Regional Profiles

North

Objective: Caquetá Depocenter structural geometry implications in prospectivity, position of the modern forebulge.

1. Quriyana-Cohembí-Platanillo--Tamarín-1-Capella-Romero.
2. Yataro-1- La Rastra-1-Rios-1991.

Central

Objective: Western Foothills and Eastern Foothills of the Eastern Cordillera and its relationship with the Putumayo basin, possible connection between Putumayo and UMV

3. Pantera-1-Catira-2- Block PUT-14.
4. San Gabriel-Costayaco-Terecay Block Programs

South

Objective: Stratigraphic traps (Pinch-outs in the Florencia High), illustrating the prospectivity already defined and the remaining.

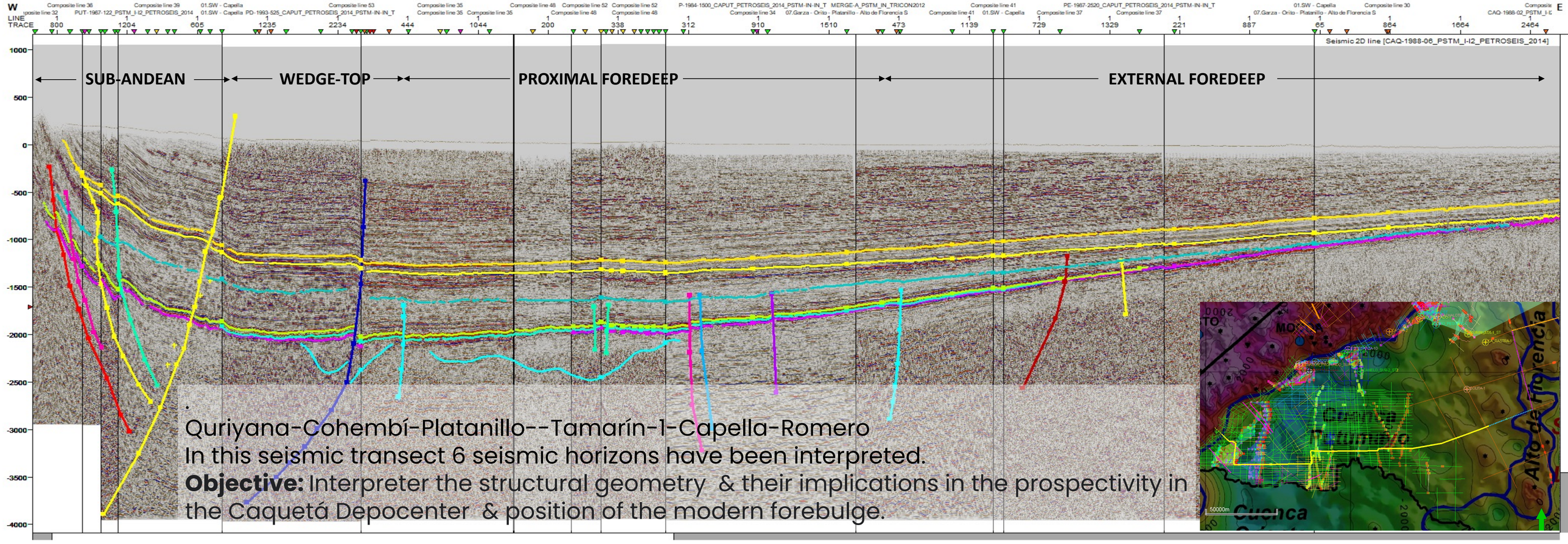
5. Conejo-1-Tacacho Block CAQ-1988-06
6. Rio Mocoa-1-Solita-1- CAQ-1988-01
7. Garza-Orito-Platanillo- Tacacho Block

Regional seismic transect (1) Part a.

Four Domains can be interpreted:

- **The sub-Andean** domain is characterized by the deformation due to the Cordillera Oriental orogeny
- **the proximal Foredeep** and **Wedge-top** domains present some depocenters beneath the Pre-Cretaceous unconformity.
- **The external Foredeep** domain is characterized by the cretaceous and Paleocene units' onlapping over the Florencia Paleo-high, which acts as a barrier even until the Eocene. The Pepino Fm. is onlapping locally over the Florencia Paleo-high, setting the stratigraphic traps.

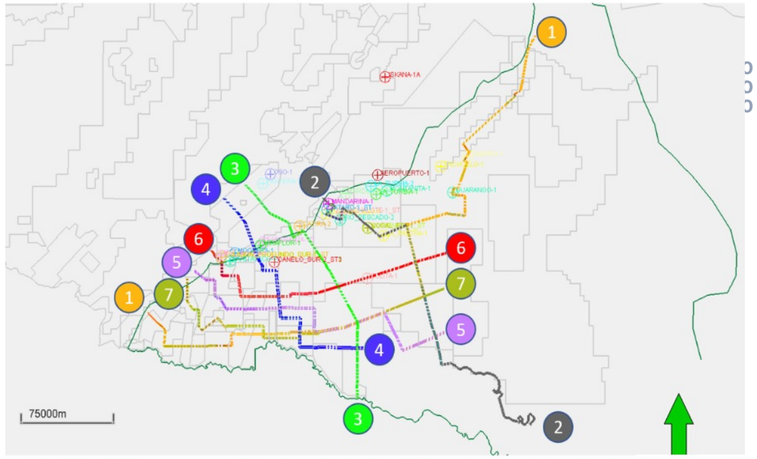
1



.

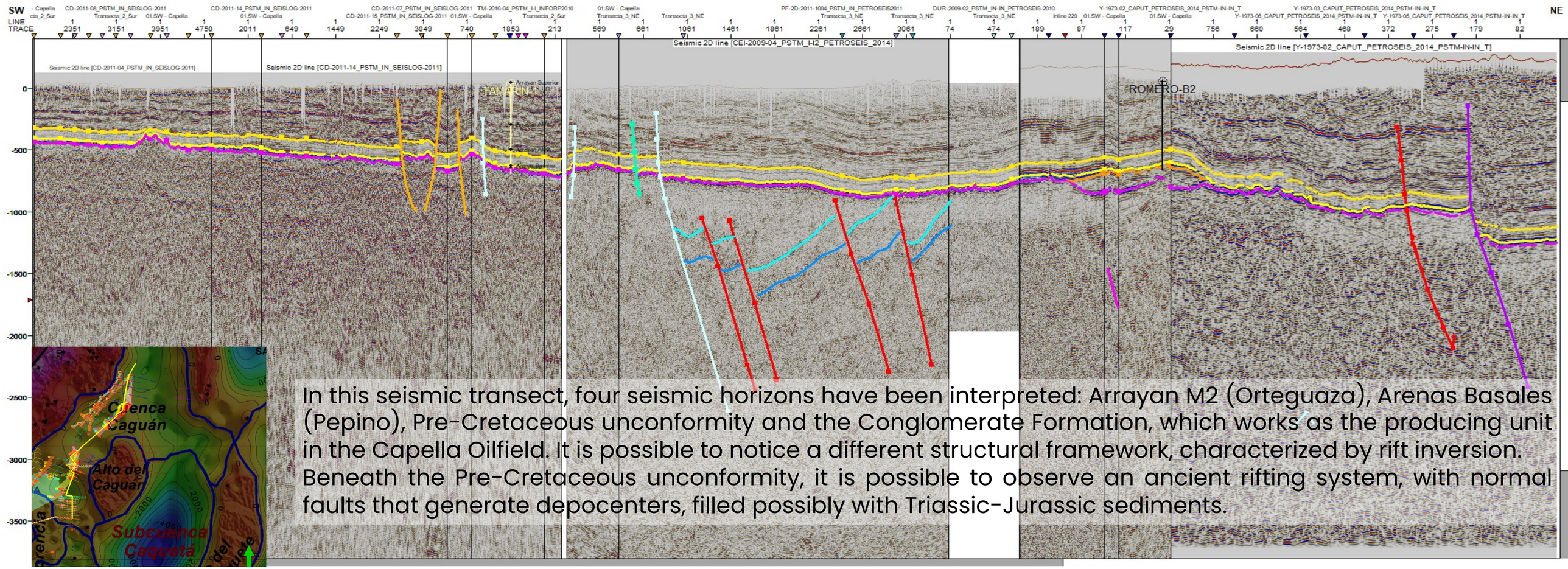
Quriyana-Cohembí-Platanillo--Tamarín-1-Capella-Romero
In this seismic transect 6 seismic horizons have been interpreted.
Objective: Interpreter the structural geometry & their implications in the prospectivity in the Caquetá Depocenter & position of the modern forebulge.

Regional seismic transect (1) part b.



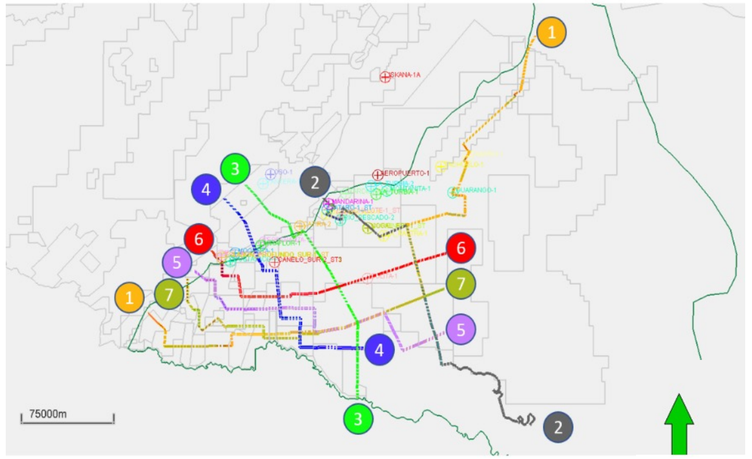
Quriyana-Cohembí-Platanillo--Tamarín-1-Capella-Romero

Objective: Caquetá Depocenter structural geometry implications in prospectivity, position of the modern forebulge.



In this seismic transect, four seismic horizons have been interpreted: Arrayan M2 (Orteguaza), Arenas Basales (Pepino), Pre-Cretaceous unconformity and the Conglomerate Formation, which works as the producing unit in the Capella Oilfield. It is possible to notice a different structural framework, characterized by rift inversion. Beneath the Pre-Cretaceous unconformity, it is possible to observe an ancient rifting system, with normal faults that generate depocenters, filled possibly with Triassic-Jurassic sediments.

Regional seismic transect (3)



3

Pantera-1 - Catira-2 - Block PUT-14.

Objective: Western Foothills and Eastern Foothills of Cordillera Oriental Range and its relationship with the Putumayo basin, stratigraphic and structural connection between Putumayo and UMV basins

NW

SE

PANTERA-1

HGS-1999-1610

OR-1991-01

CAQ-1988-04

PR-1988-1330

40 Km

20 Km

Pepino

Villeta

Orteguaza

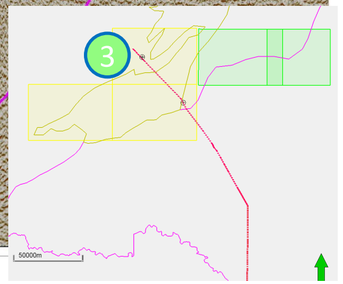
Rumiyaco

Pre-Cretaceous Unconformity

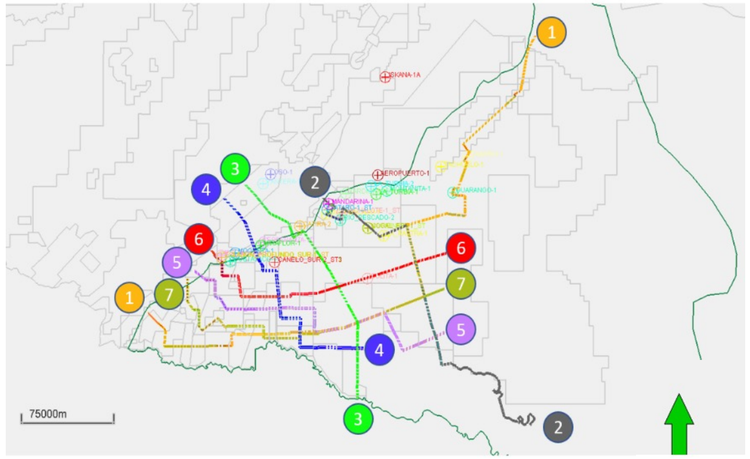
0 2 4 6 8 10 Km

1:200.000

The stratigraphic description of the Cretaceous rocks in the UMV and the Putumayo basins shows similar characteristics: these rocks are present in the interpretation of seismic information in both basins with a tipical pattern of a wedge that thins to the east



Regional seismic transect (3)

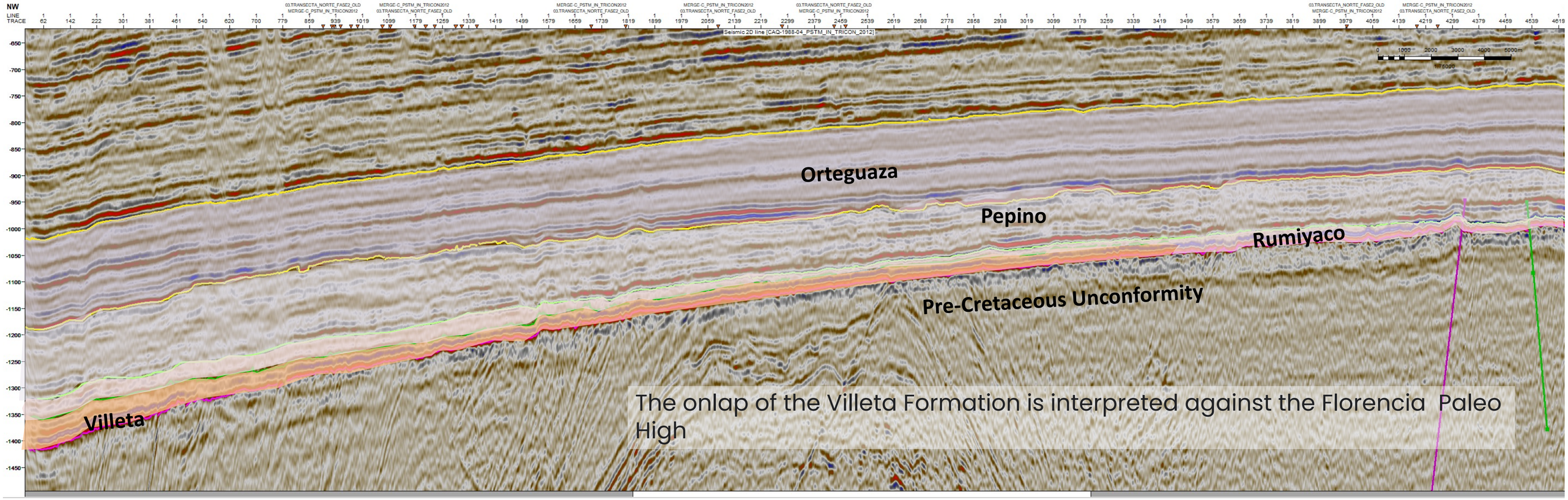


3

Pantera-1 - Catira-2 - Block PUT-14.

Objective: Western Foothills and Eastern Foothills of Cordillera Oriental Range and its relationship with the Putumayo basin, stratigraphic and structural connection between Putumayo and UMV basins

CAQ-1988-04

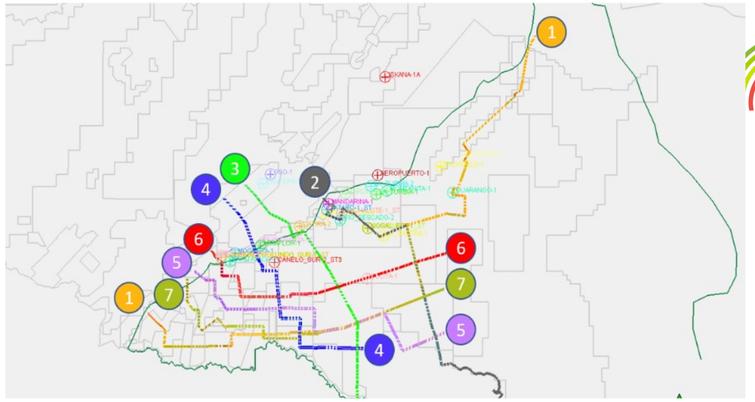


The onlap of the Villeta Formation is interpreted against the Florencia Paleo High

Regional seismic transect (6)

Regional seismic Transect 6.
Rio Mocoa-1-Solita-1- CAQ-1988-01

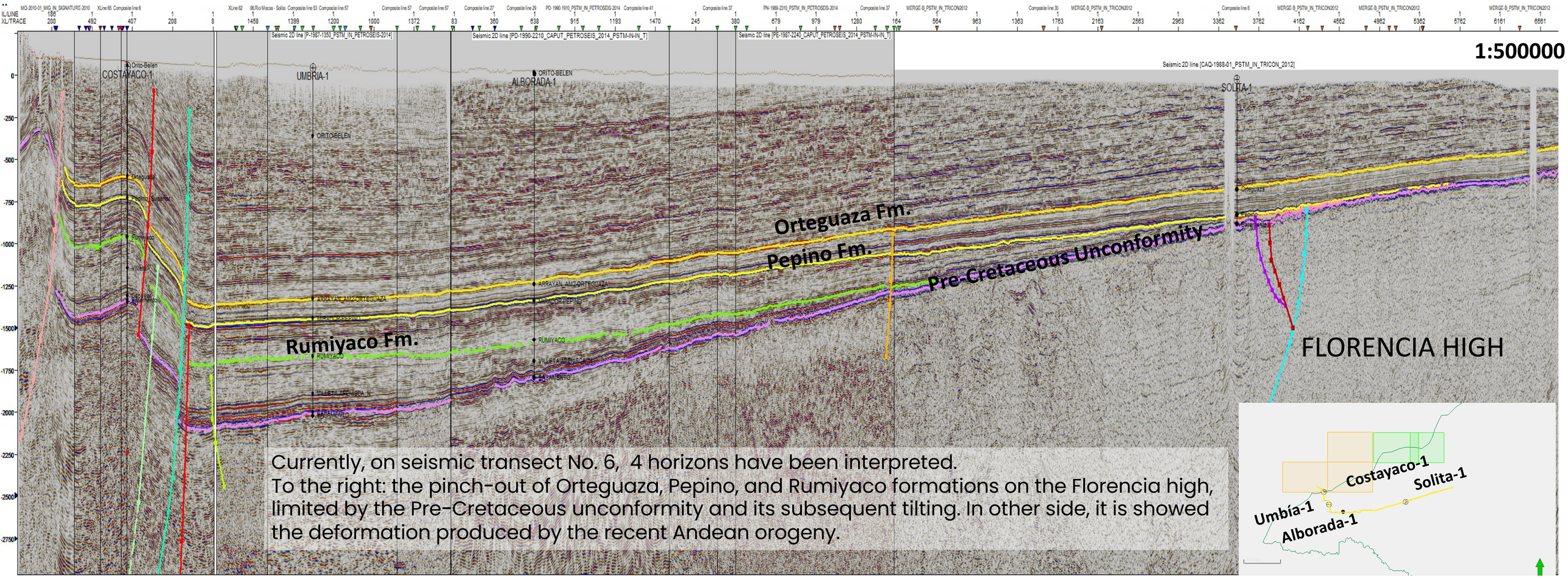
Objective: Stratigraphic traps (pinchouts on the Florencia High), illustrating the prospectivity already defined and remaining.



6

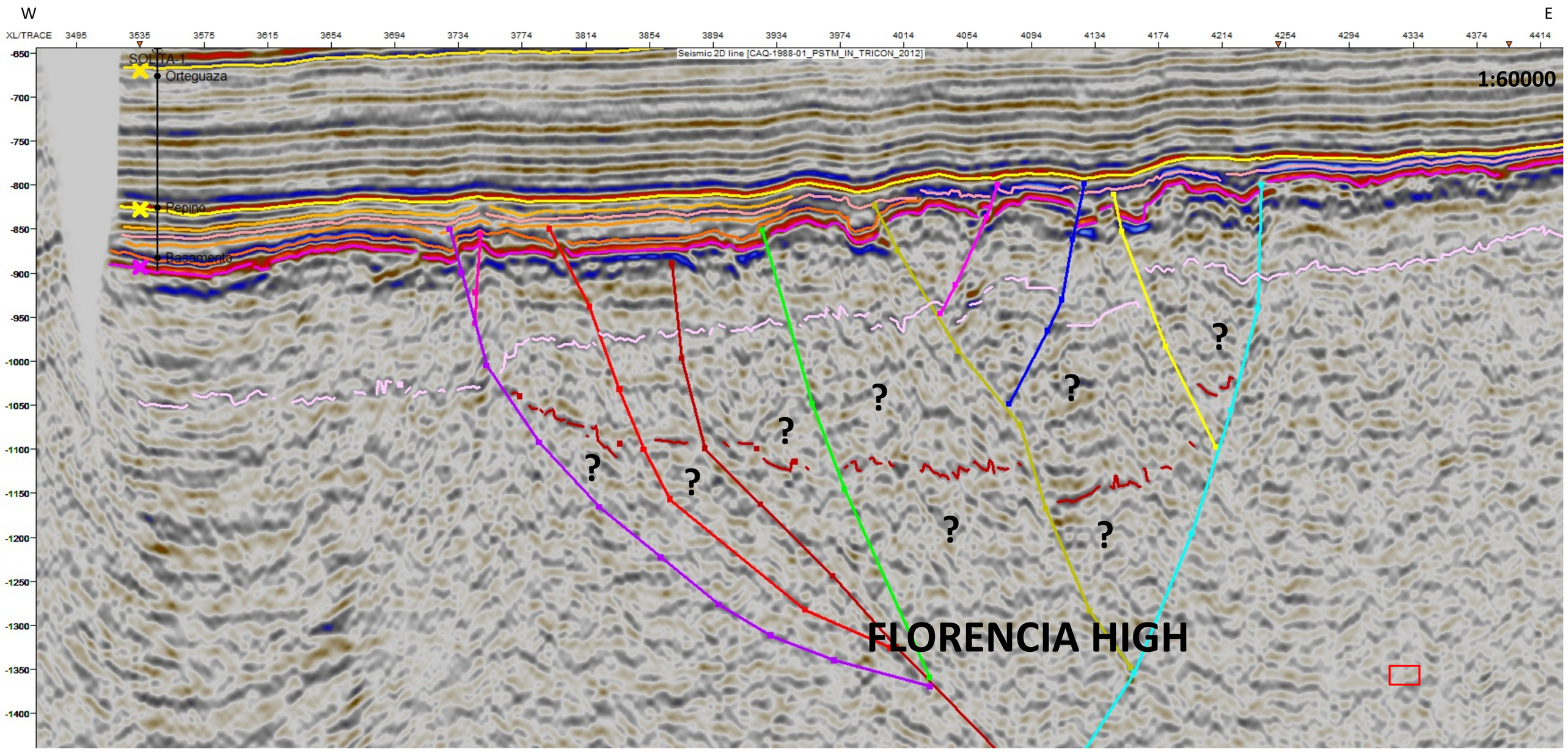
W E

1:500000

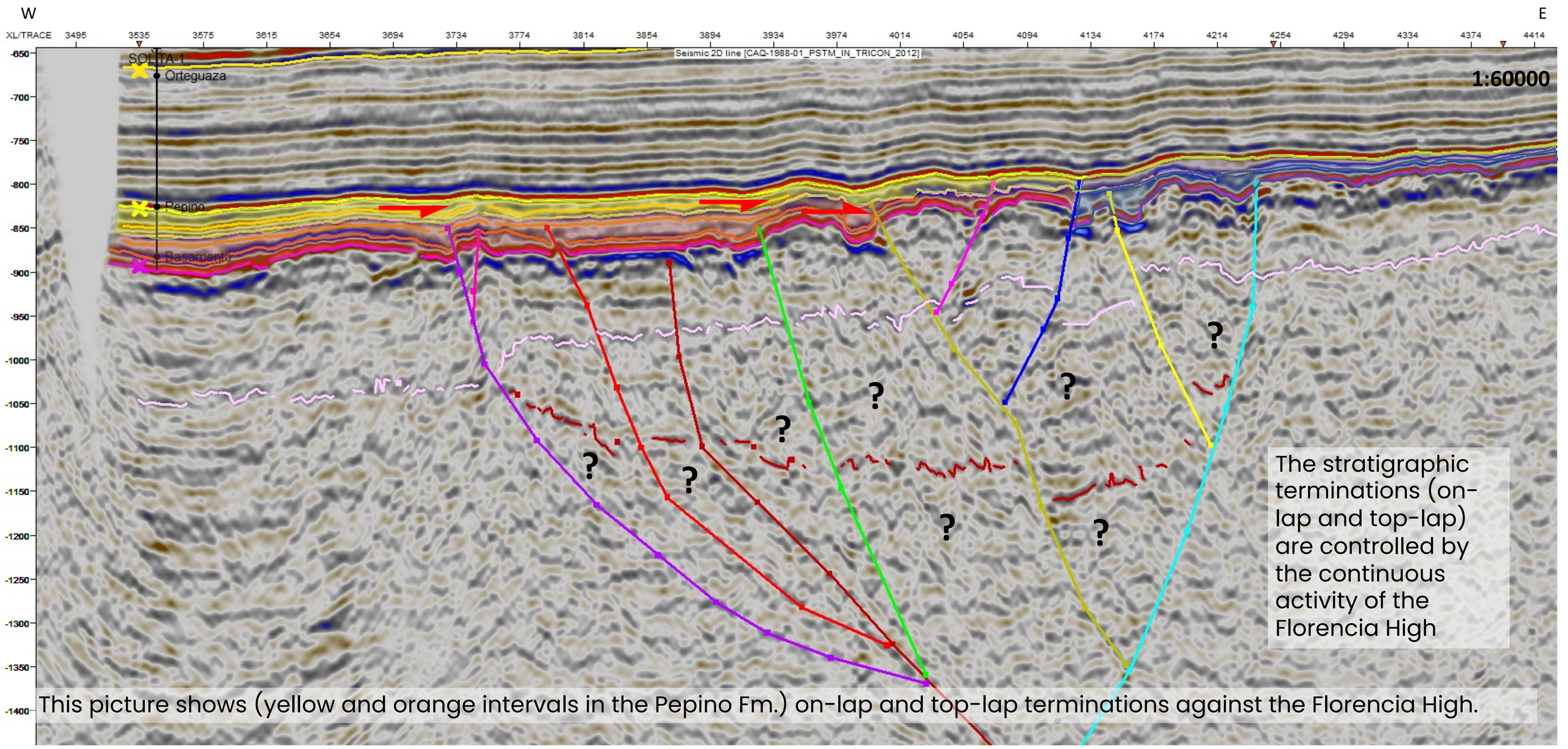


Currently, on seismic transect No. 6, 4 horizons have been interpreted.
To the right: the pinch-out of Orteguaza, Pepino, and Rumiyaco formations on the Florencia high, limited by the Pre-Cretaceous unconformity and its subsequent tilting. In other side, it is showed the deformation produced by the recent Andean orogeny.

Stratigraphic terminations on Florencia paleo-high

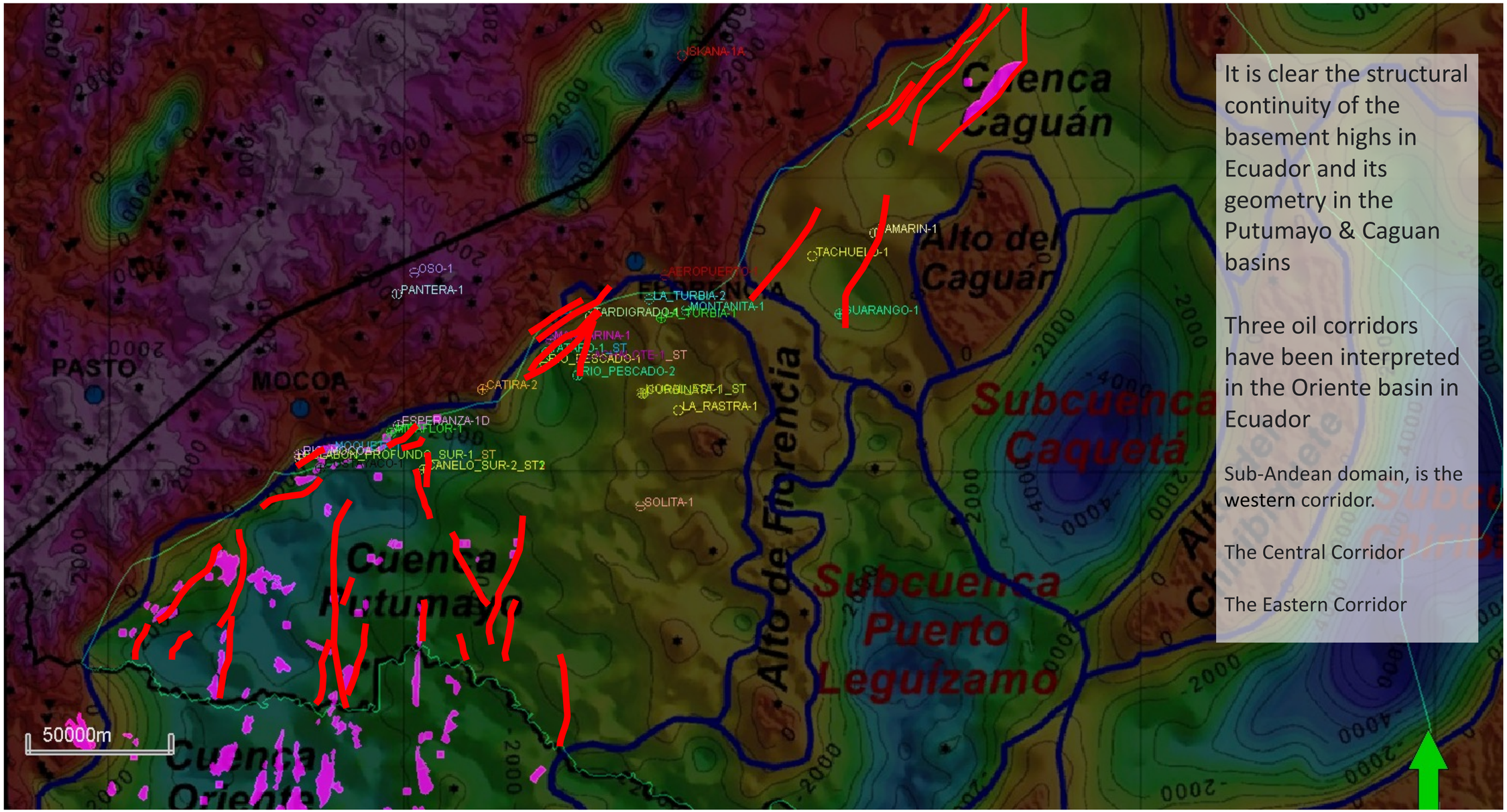


Stratigraphic terminations on Florencia High



This picture shows (yellow and orange intervals in the Pepino Fm.) on-lap and top-lap terminations against the Florencia High.

Structural framework



It is clear the structural continuity of the basement highs in Ecuador and its geometry in the Putumayo & Caguan basins

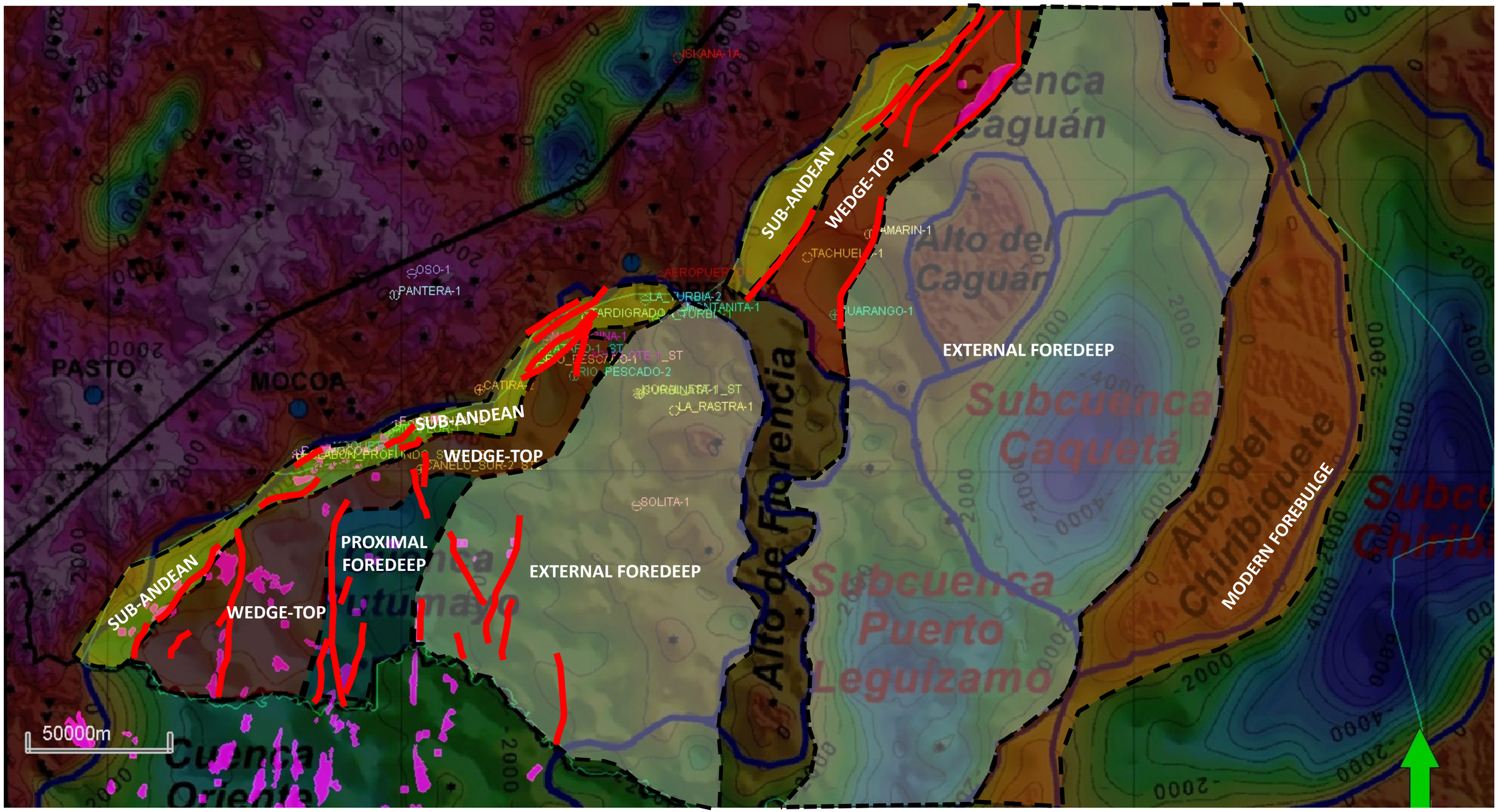
Three oil corridors have been interpreted in the Oriente basin in Ecuador

Sub-Andean domain, is the **western** corridor.

The Central Corridor

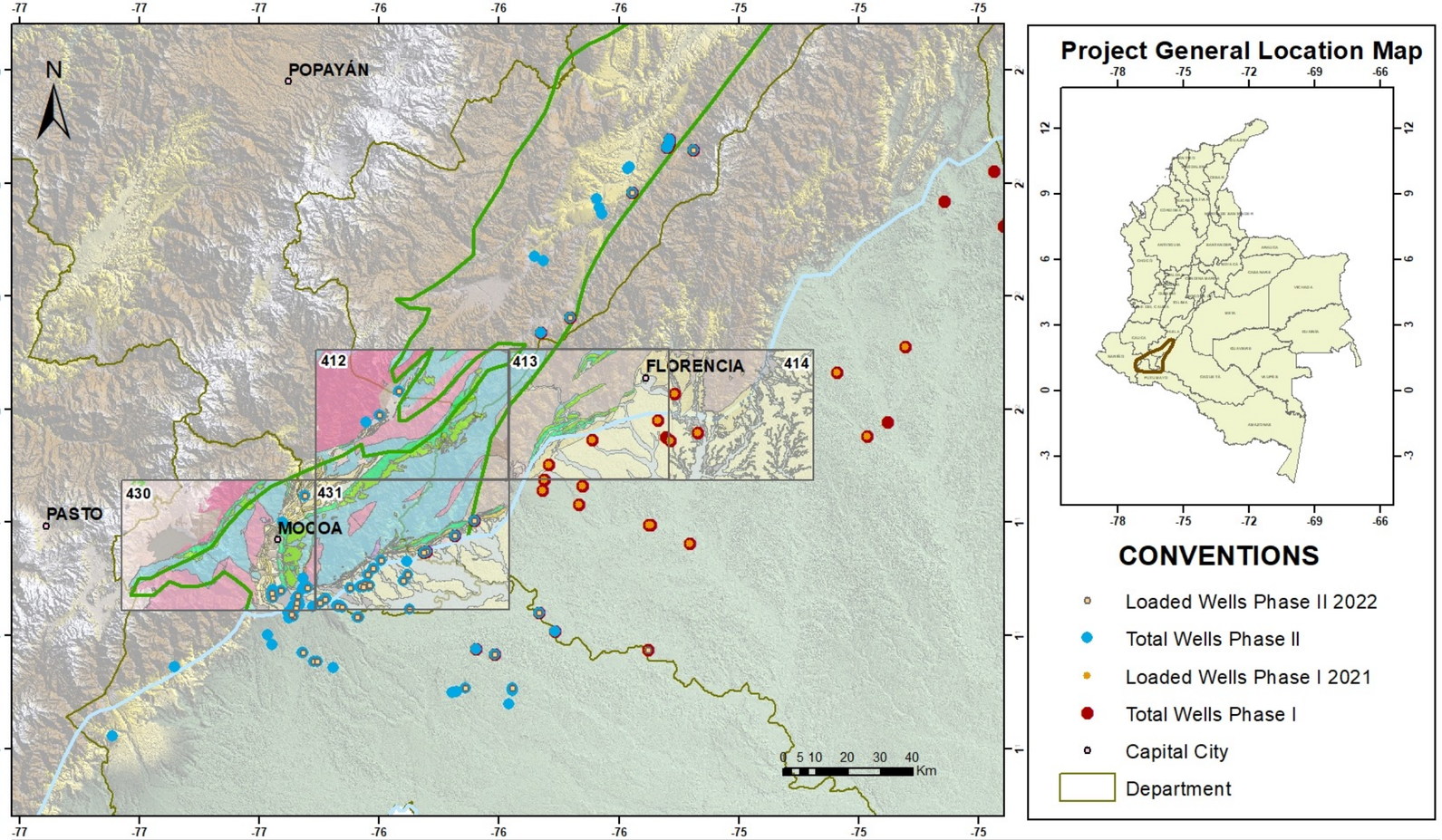
The Eastern Corridor

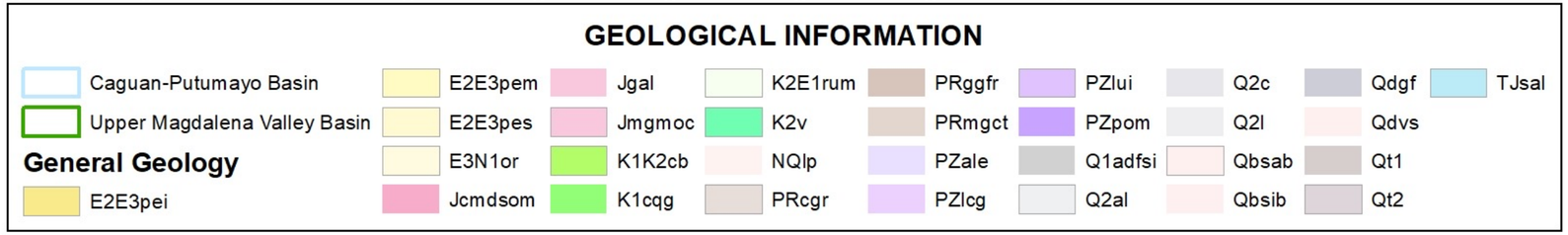
Structural framework



Well Data

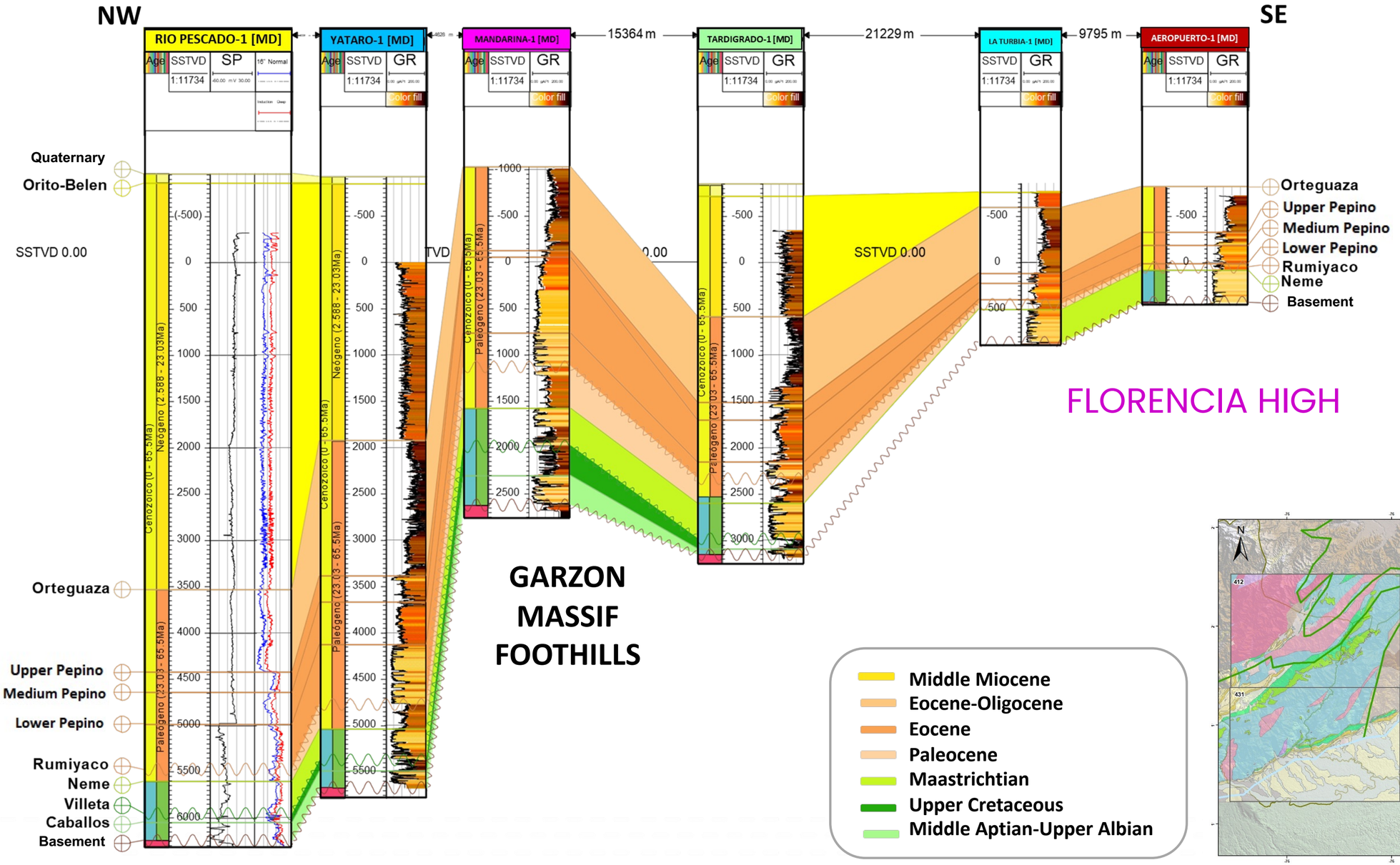
Location of subsurface information



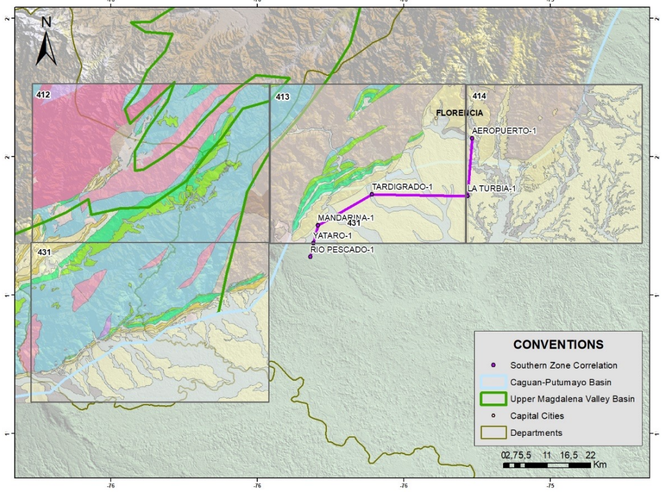


Phase	Total wells	Verified wells	Loaded Wells Petrel
I	634	149	22
II	218	89	56

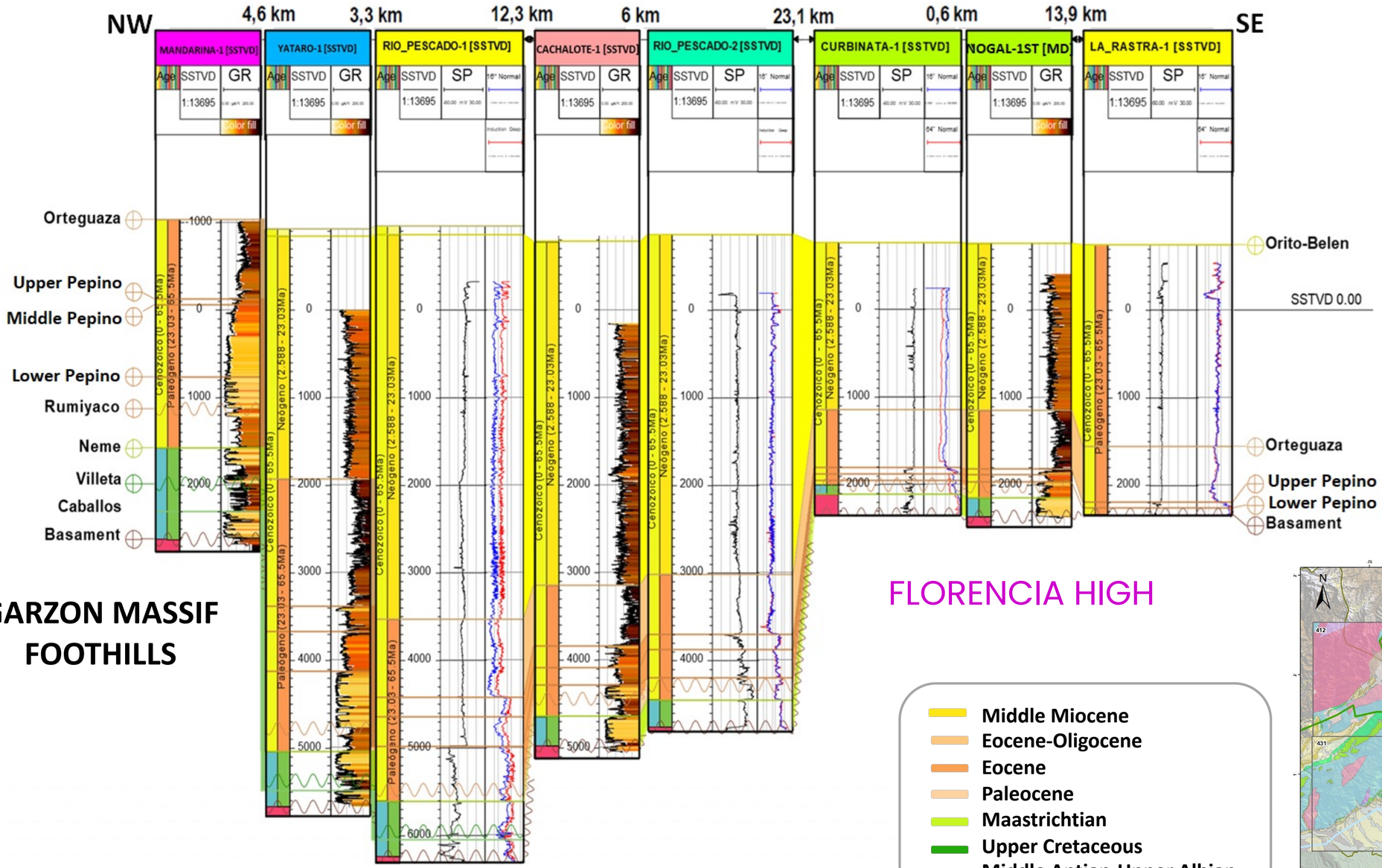
Structural correlation - southern zone



- Middle Miocene
- Eocene-Oligocene
- Eocene
- Paleocene
- Maastrichtian
- Upper Cretaceous
- Middle Aptian-Upper Albian



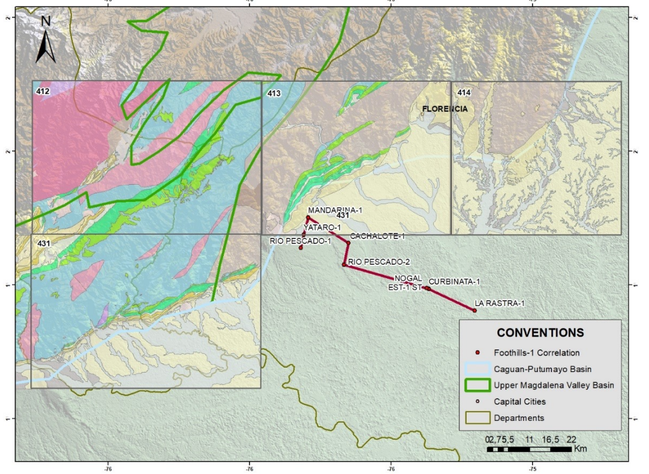
Structural correlation - Foothills I



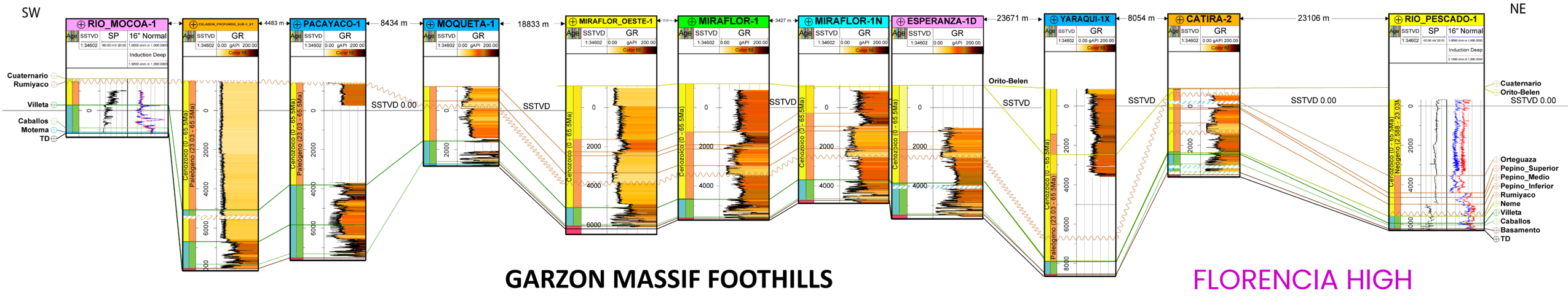
GARZON MASSIF
FOOTHILLS

FLORENCIA HIGH

- Middle Miocene
- Eocene-Oligocene
- Eocene
- Paleocene
- Maastrichtian
- Upper Cretaceous
- Middle Aptian-Upper Albian



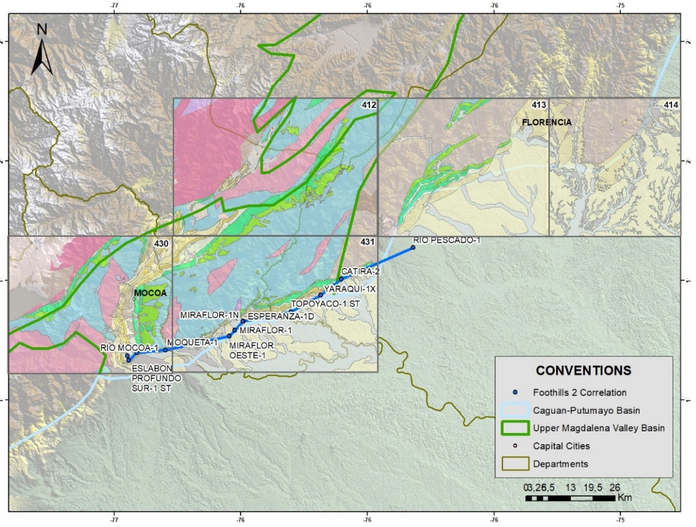
Structural correlation - Foothills II

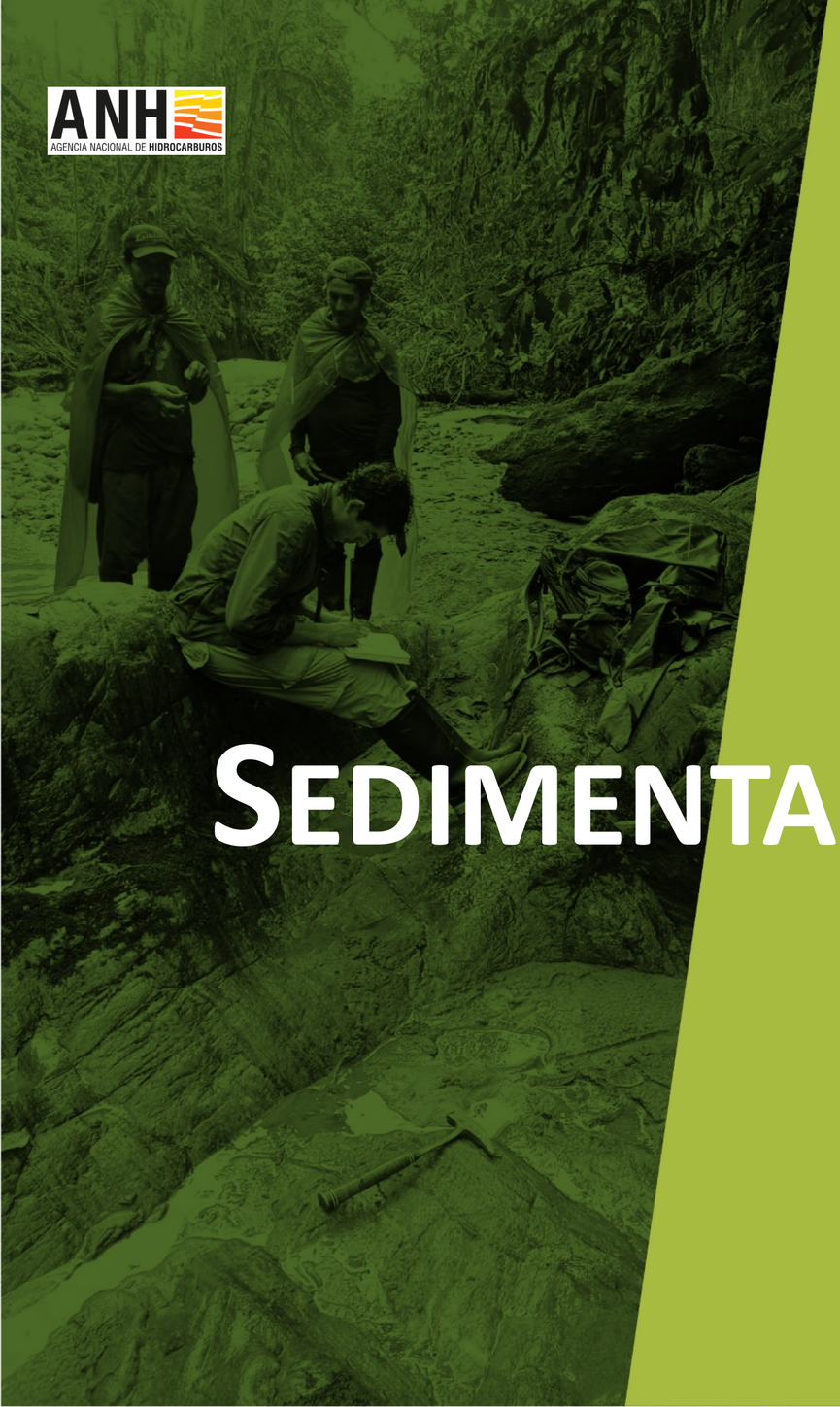


GARZON MASSIF FOOTHILLS

FLORENCIA HIGH

- Middle Miocene
- Eocene-Oligocene
- Eocene
- Paleocene
- Maastrichtian
- Upper Cretaceous
- Middle Aptian-Upper Albian

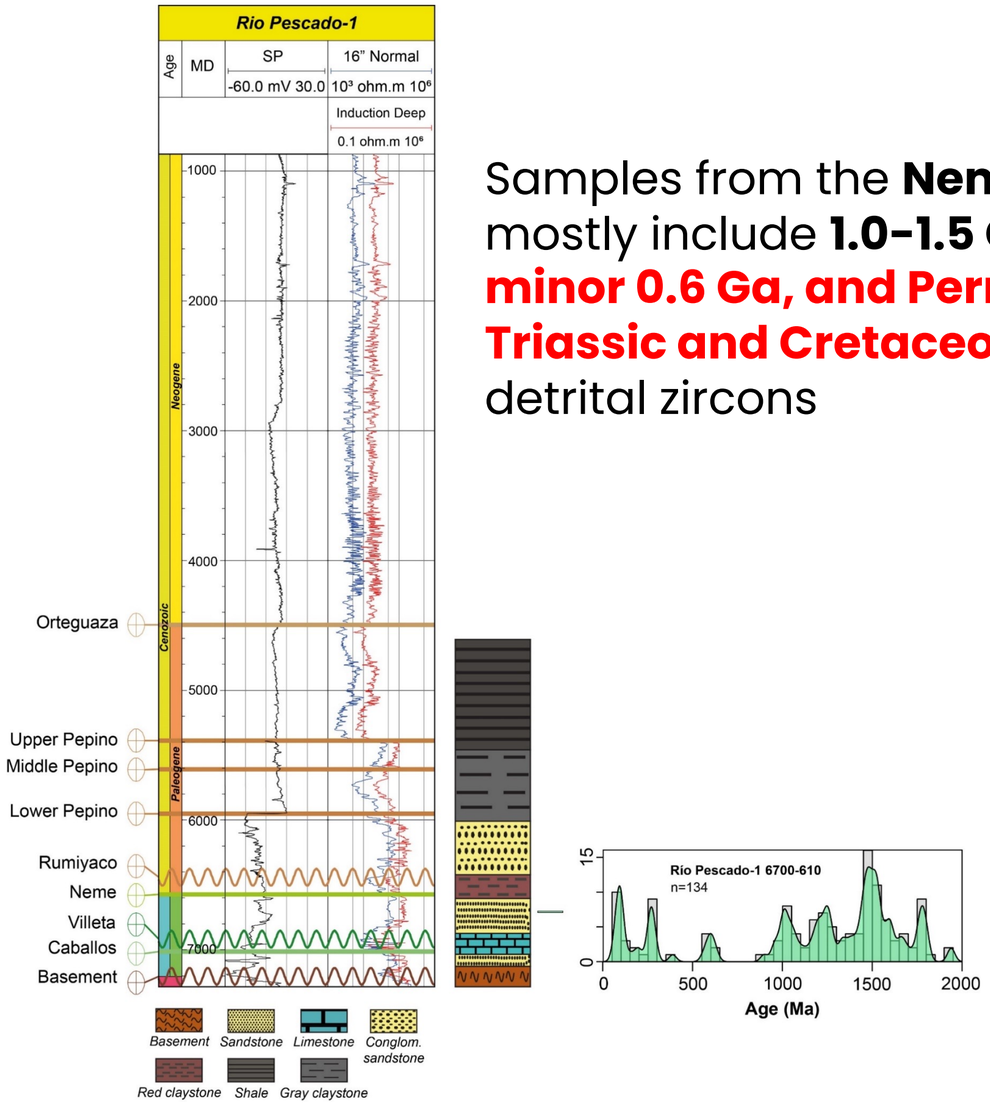




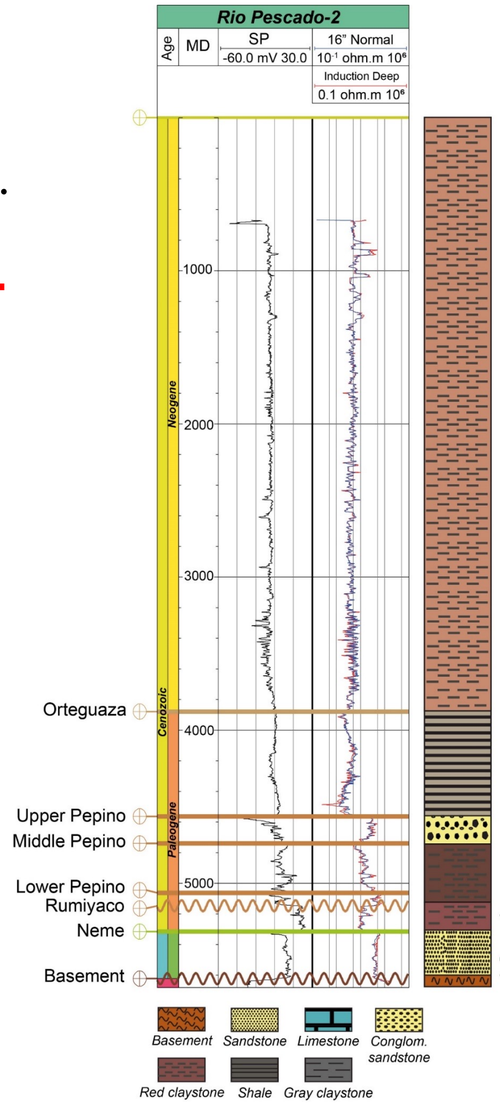
SEDIMENTARY PROVENANCE

Multi-Method Provenance Analysis

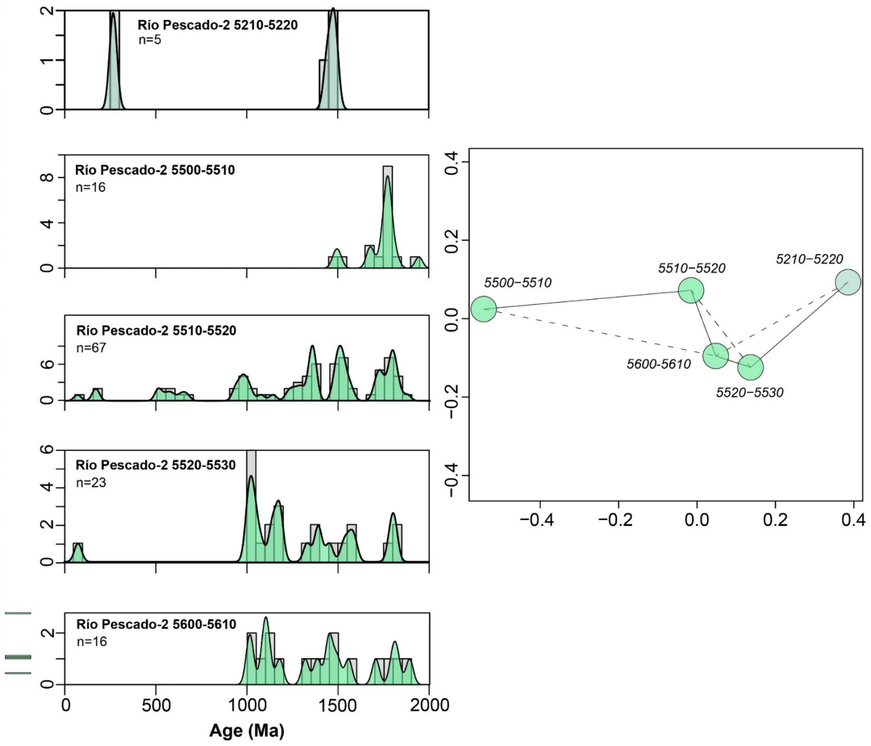
Detrital zircon U-Pb geochronology from borehole samples



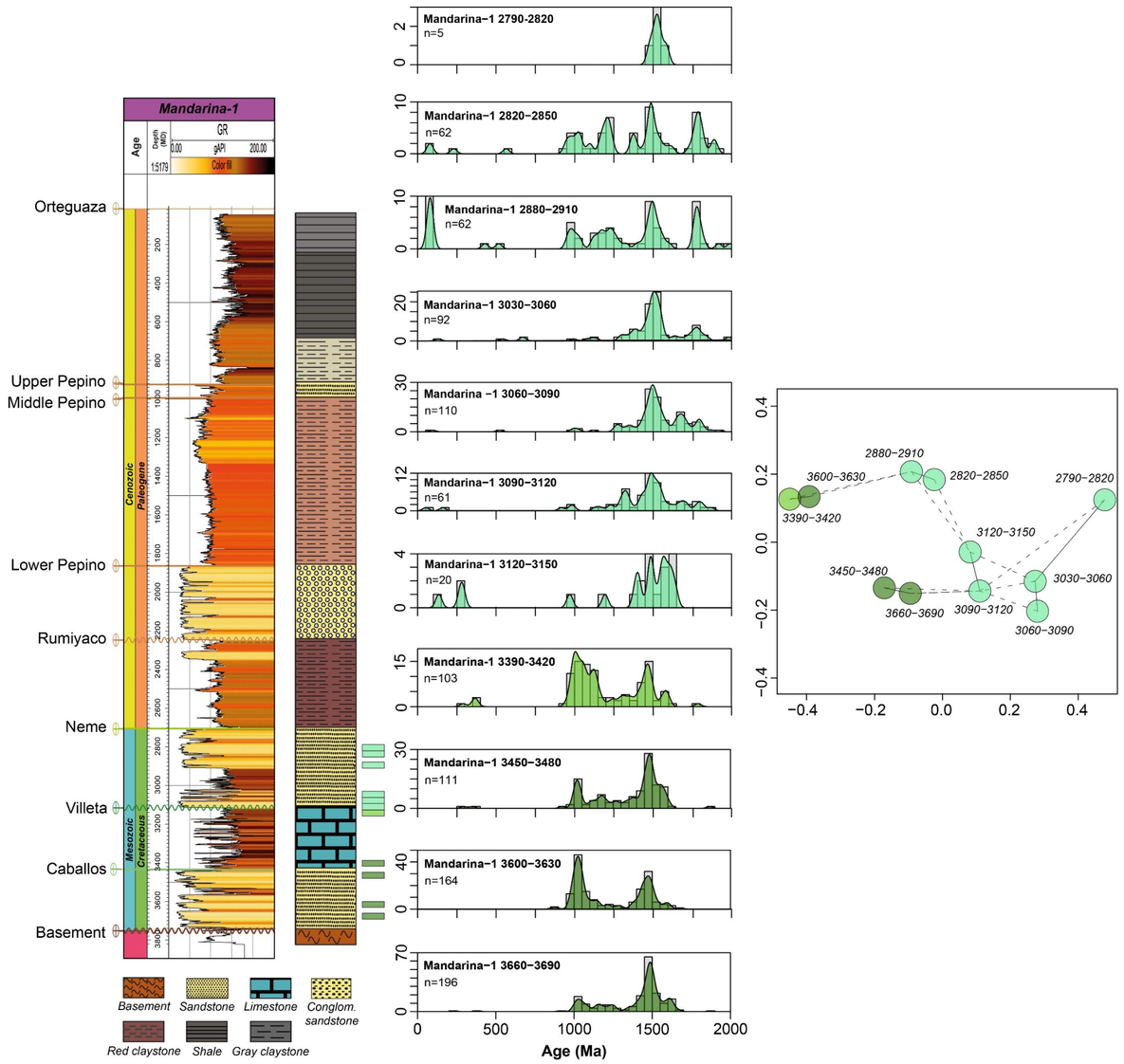
Samples from the **Neme Fm.** mostly include **1.0-1.5 Ga, minor 0.6 Ga, and Permian-Triassic and Cretaceous** detrital zircons



Poor yield from one sample of the Rumiyaco Fm., with **only three ~1.5 Ga zircons and two Permian individual ages**



Detrital zircon U-Pb geochronology from borehole samples



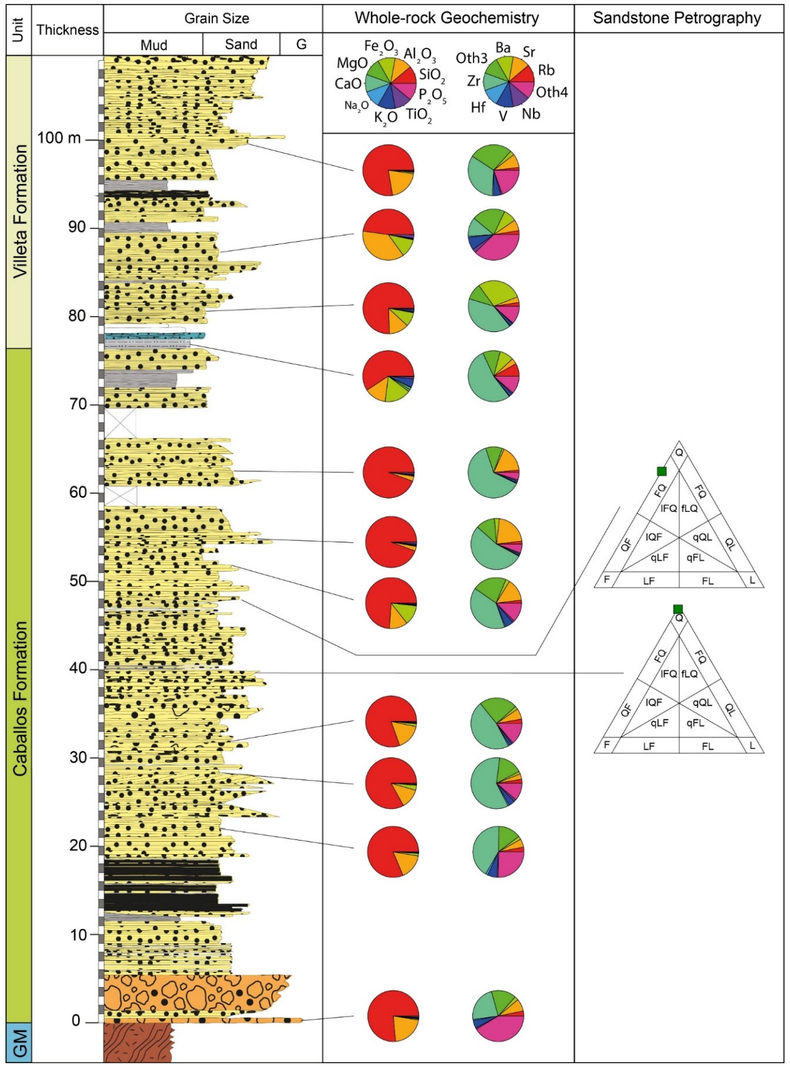
Samples from the **Caballos Fm.** mostly include **1.0–1.5 Ga detrital zircons**

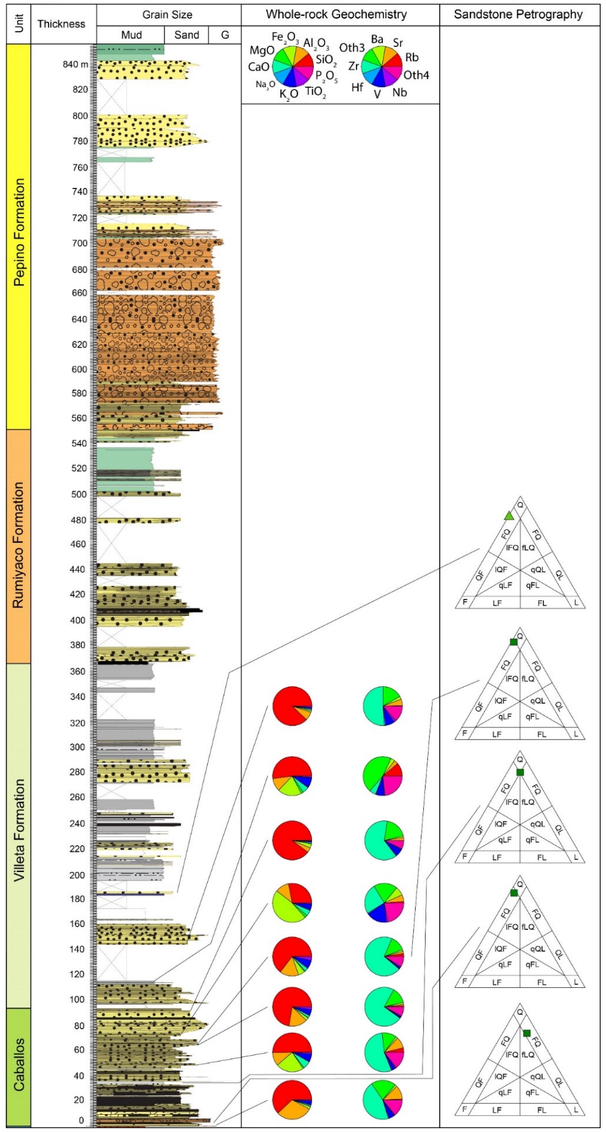
The **Villeta and Neme Fms.** records a relative **depletion of ~1.0 Ga**

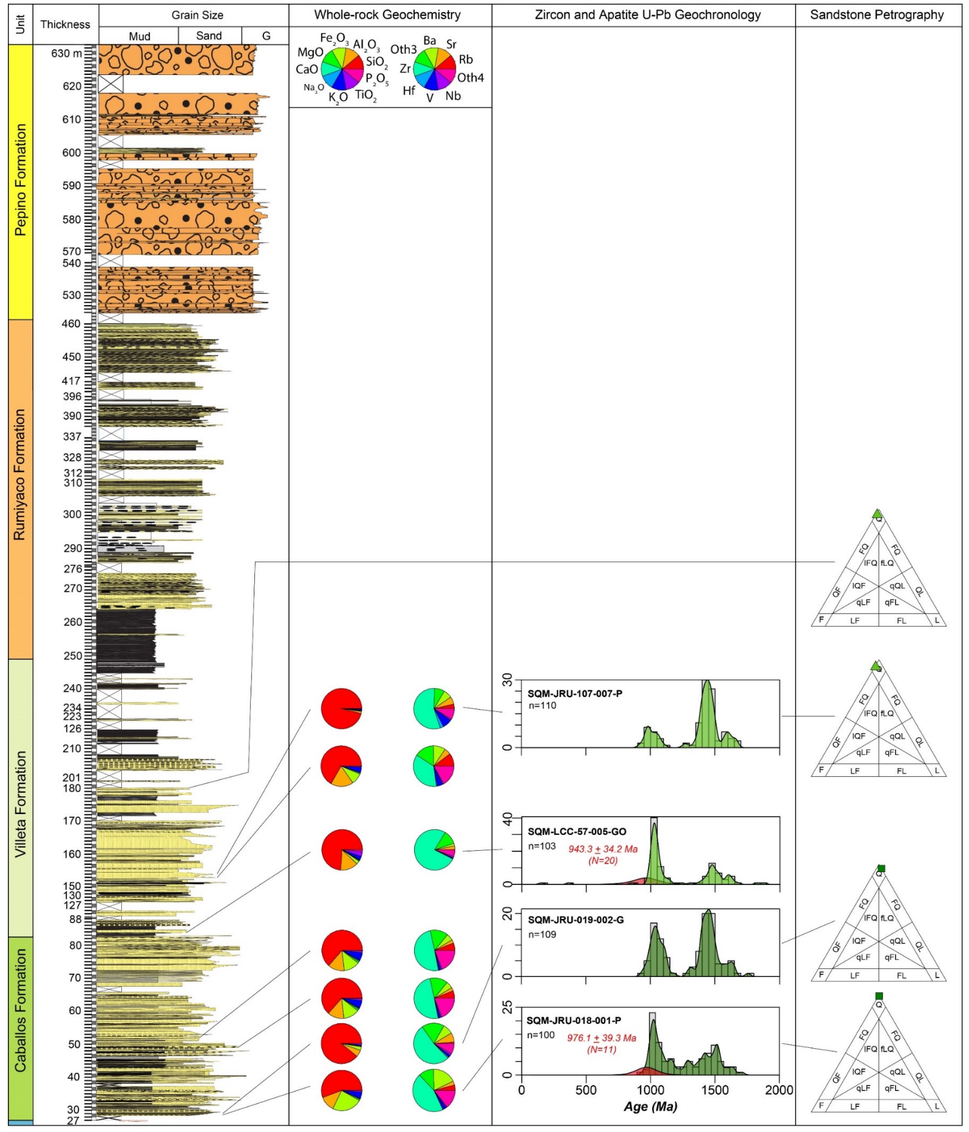
Sandstones from the **Caballos Fm. are similar to those of the Villeta Fm. in terms of their zircon detrital age** distributions, but **strongly differ** from the detrital zircon spectra **from the overlying when Neme Fm.**

Multi-Method Provenance Analysis

Petrography, geochemistry and detrital zircon U-Pb geochronology from samples collected from stratigraphic sections

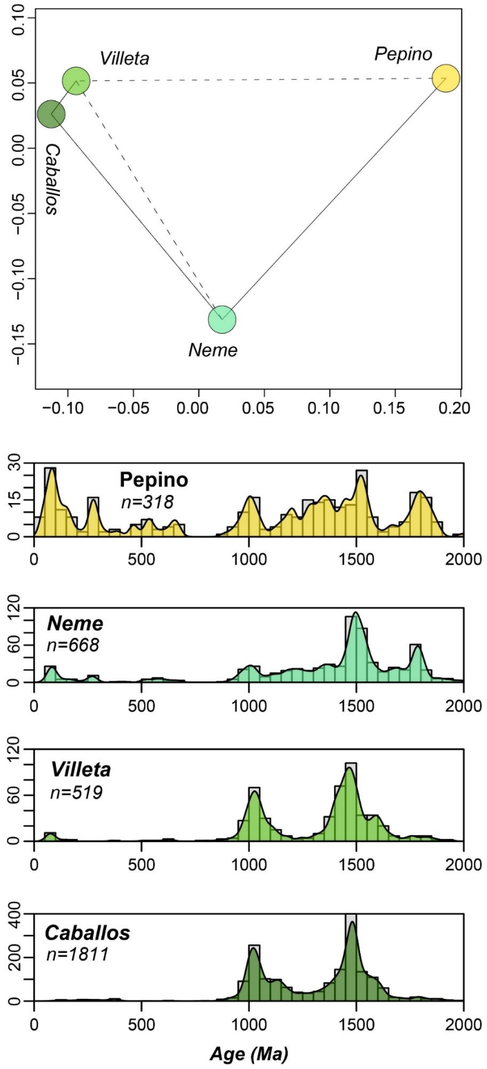


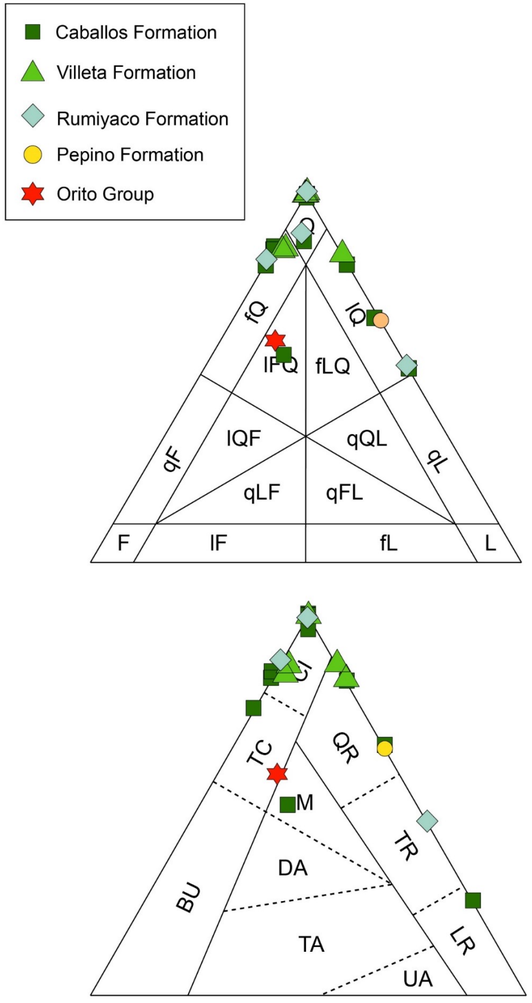


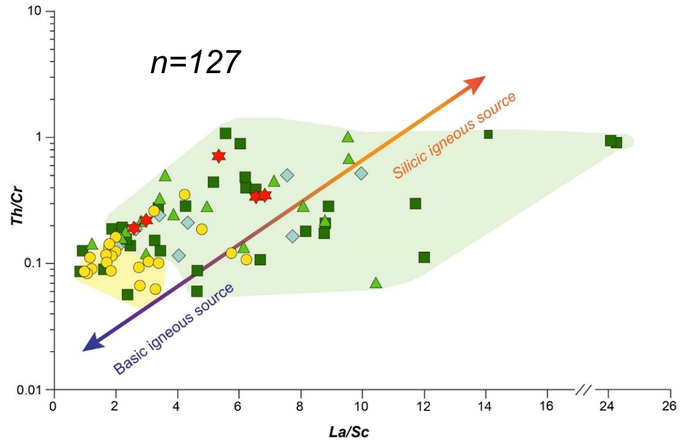


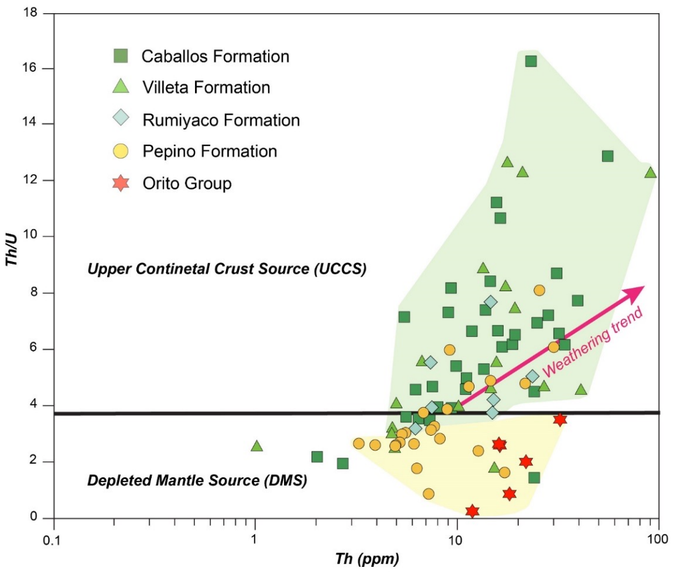
Multi-Method Provenance Analysis

Integration of samples from boreholes, stratigraphic sections, and regional sampling









The **Caballos and Villeta Fms.** have similar provenance represented by **compositionally evolved units (mostly cratonic)**

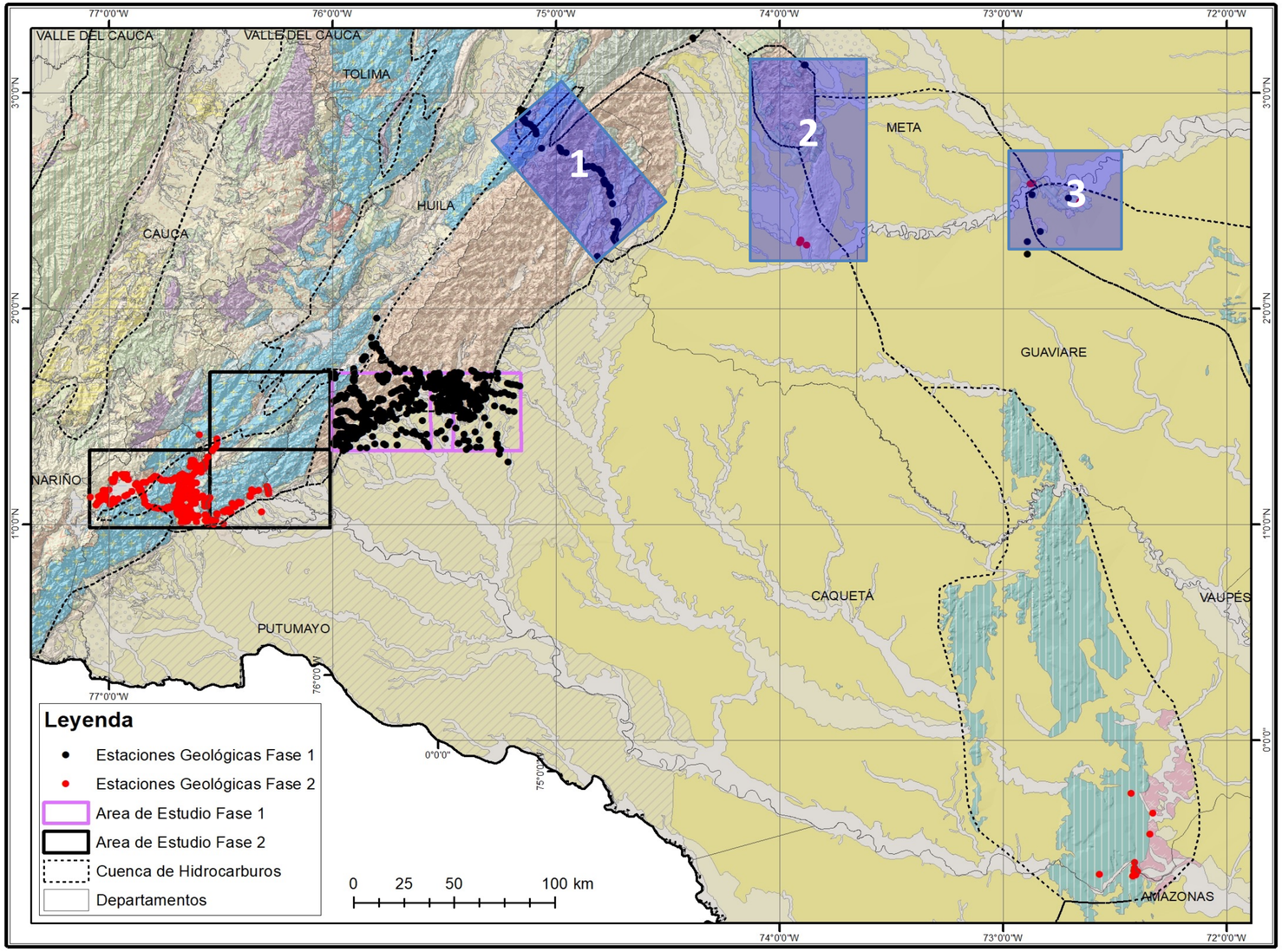
The **Eocene Pepino Fm.** received detrital material from young and **compositionally juvenile sources (Central Cordillera)**

The **Neme and Rumiyaco Fms**. have a **transitional signal** and record the early change in the source areas configuration

INVERSE THERMAL MODELING

Inverse Thermal Modeling

Thermal reconstructions from apatite fission-track and zircon (U-Th)/He data



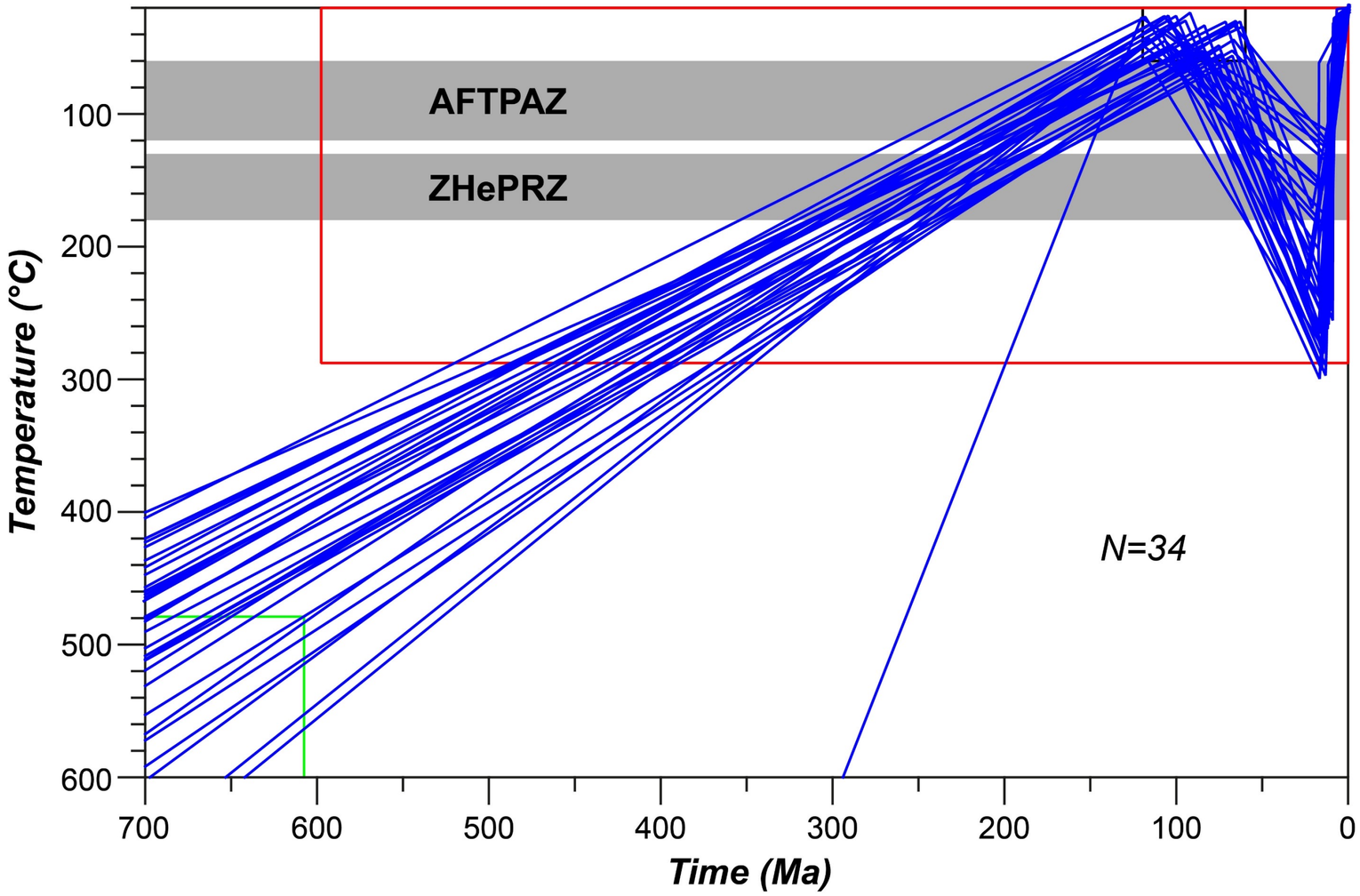
Regional sampling of Proterozoic rocks exposed along **basement highs towards the margins of the basin**

1. Garzon Massif
2. Macarena Range
3. Guaviare Complex (Vaupes High)

Additional geological constraints such as **cross-cutting relationships** were considered for the thermal modeling

Inverse Thermal Modeling

Thermal history of the Garzon Massif



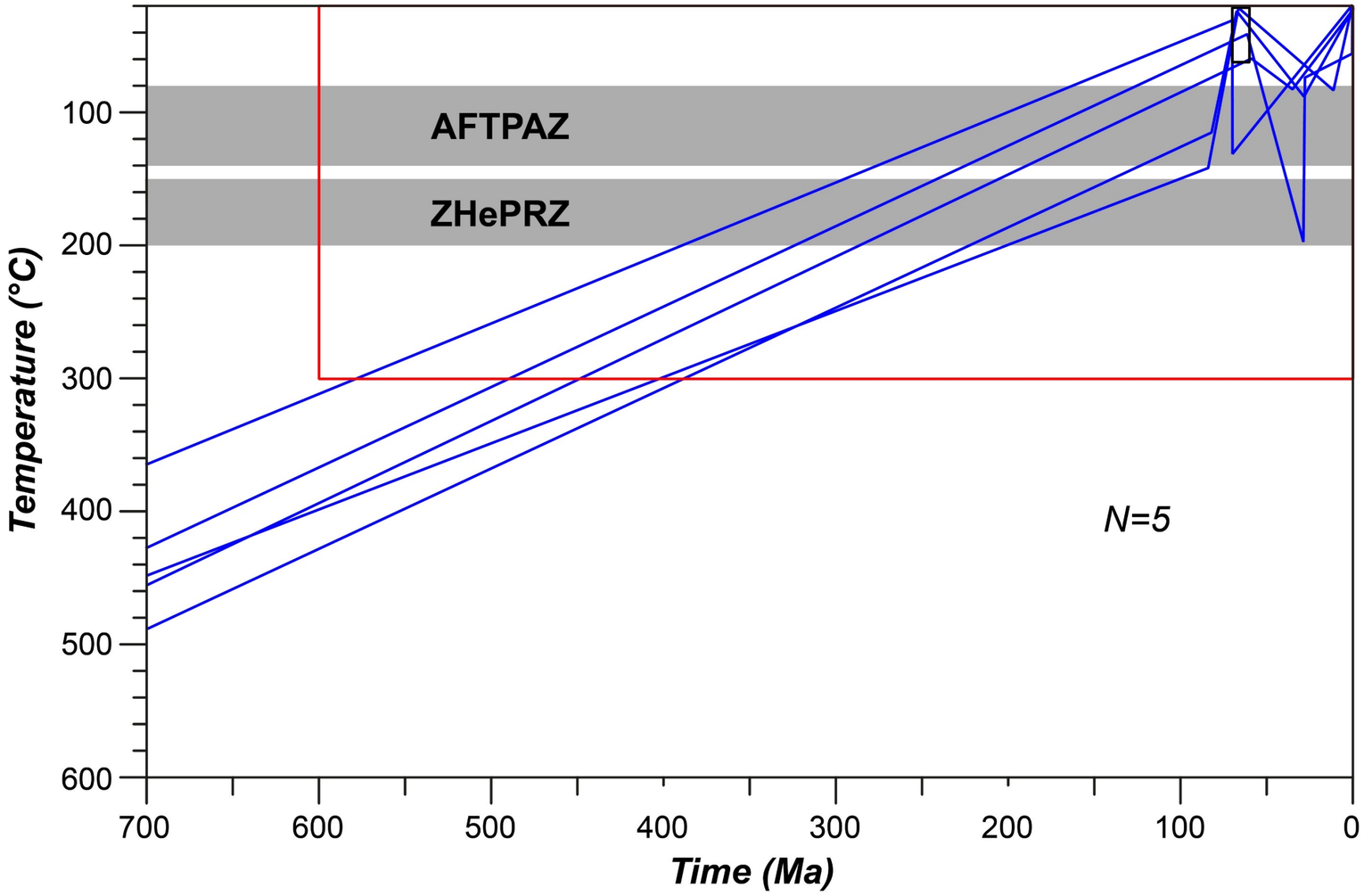
Proterozoic rocks were **at or near the surface during the accumulation of Cretaceous strata**

Analyzed samples were **buried/reheated** to **temperatures above the APAZ (~60-120°C)** due to the accumulation of thick Paleogene sequences (e.g., Pepino Fm.)

Onset of rapid exhumation during the middle Miocene (~15-10 Ma)

Inverse Thermal Modeling

Thermal history of the Macarena Range



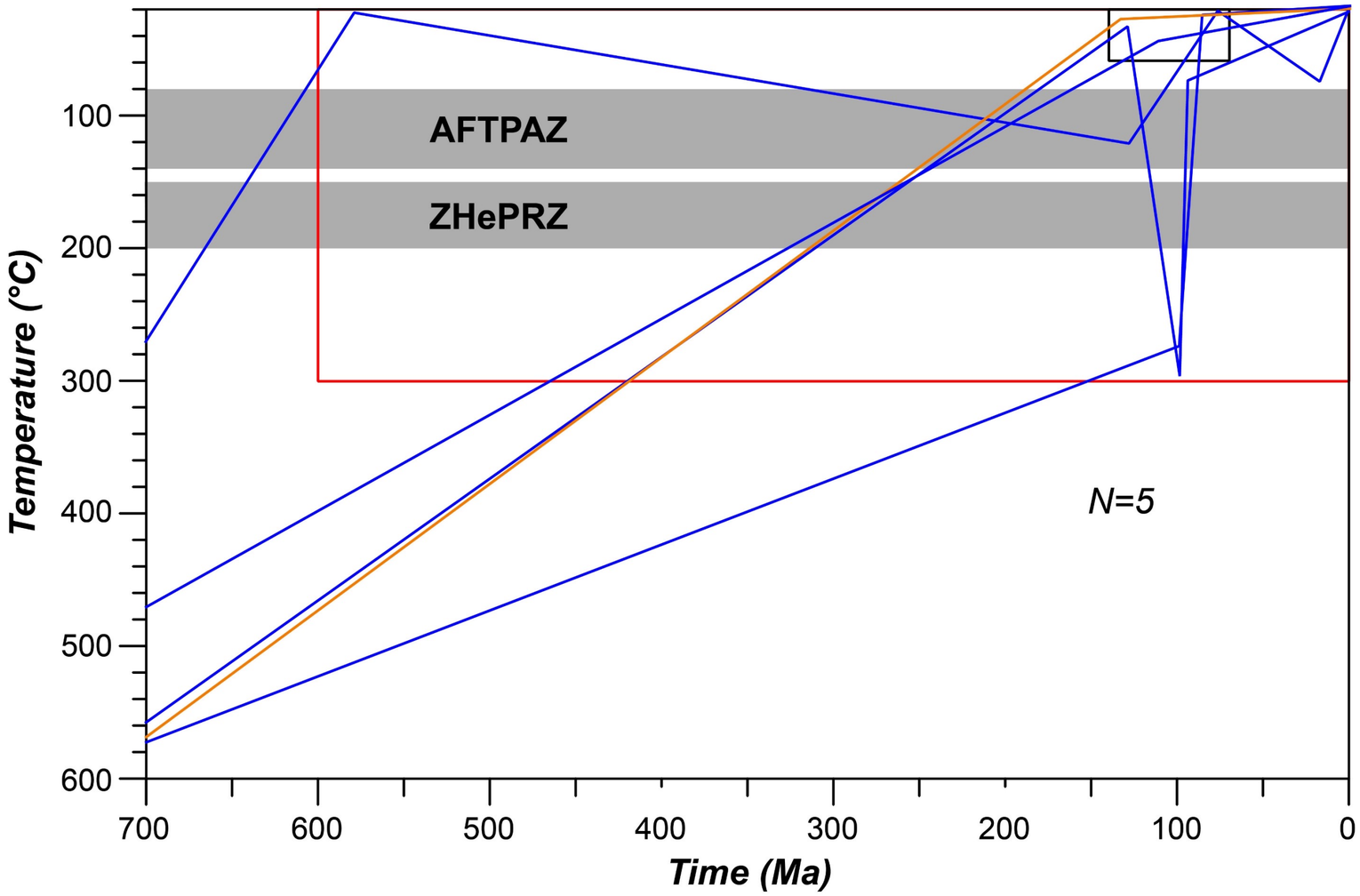
Proterozoic rocks were **at or near the surface during the accumulation of Upper Cretaceous-Paleocene sediments** (Neme Fm.-Palmichal Group?)

Most samples **were buried/reheated** to **temperatures within the APAZ (~60-120°C)** as suggested by the presence of **partially reset cooling ages and short fission tracks**

Onset of exhumation seemingly started during the Oligocene-early Miocene (~30-20 Ma)

Inverse Thermal Modeling

Thermal history of the Guaviare Complex (Vaupes High)



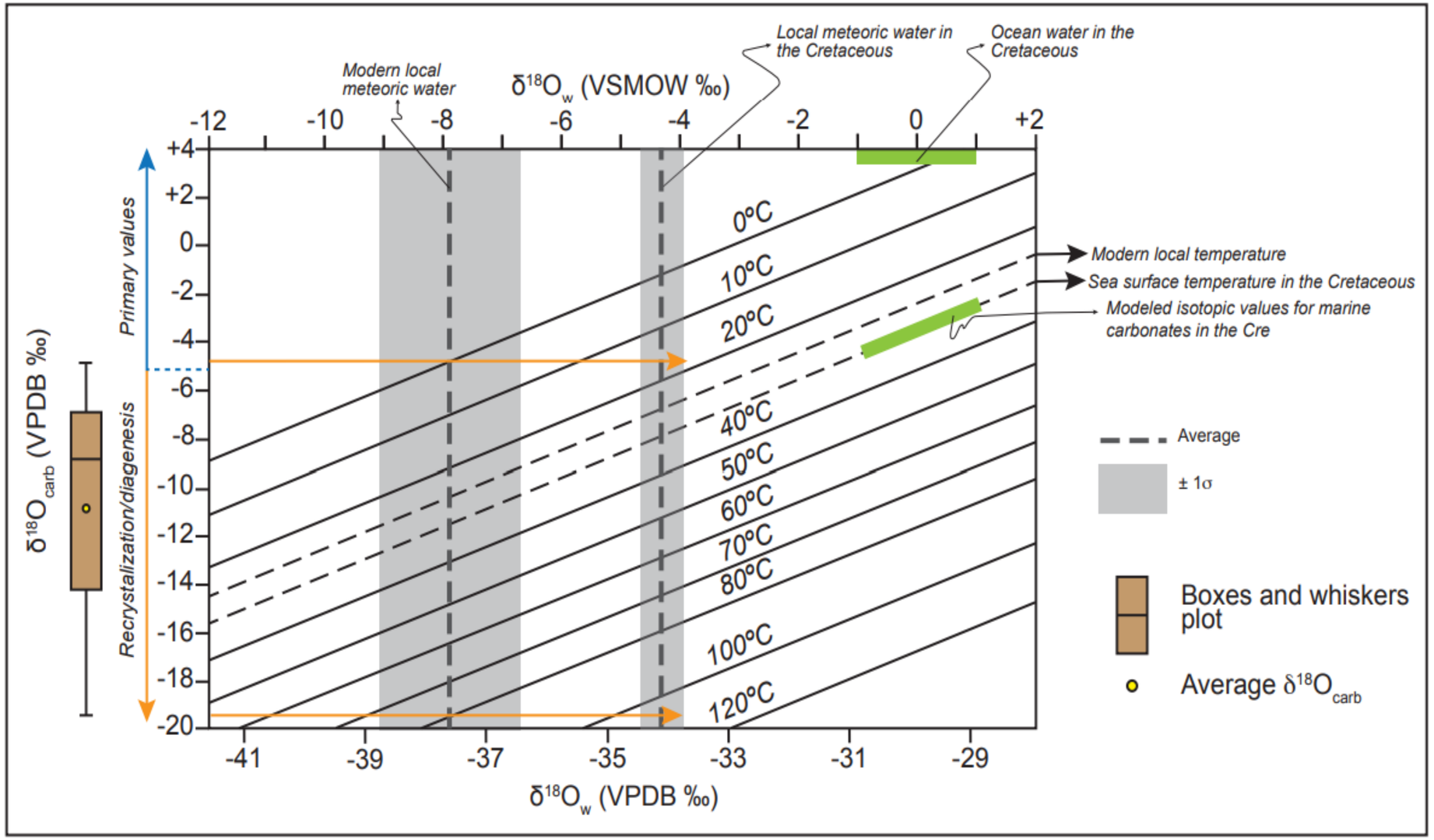
Proterozoic rocks were **at or near the surface during the accumulation of the San José Fm. (Cretaceous ??)**.

Samples were likely **buried/reheated** to **temperatures within or below the APAZ (~60-120°C)** as suggested by the presence of **partially to non reset cooling ages**.

It seems that the **SJ Fm. was never reheated to temperatures within the APAZ** (i.e., **thin Cenozoic sedimentary cover**)

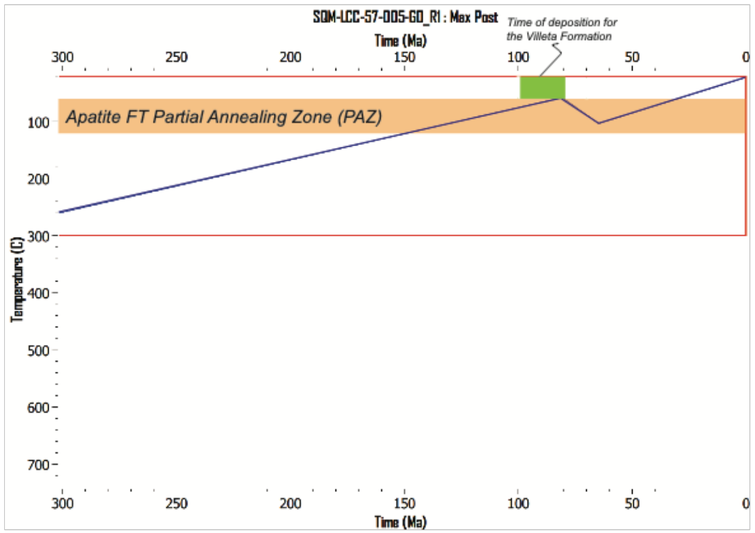
STABLE ISOTOPES, BURIAL TEMPERATURES, AND THERMAL MATURITY

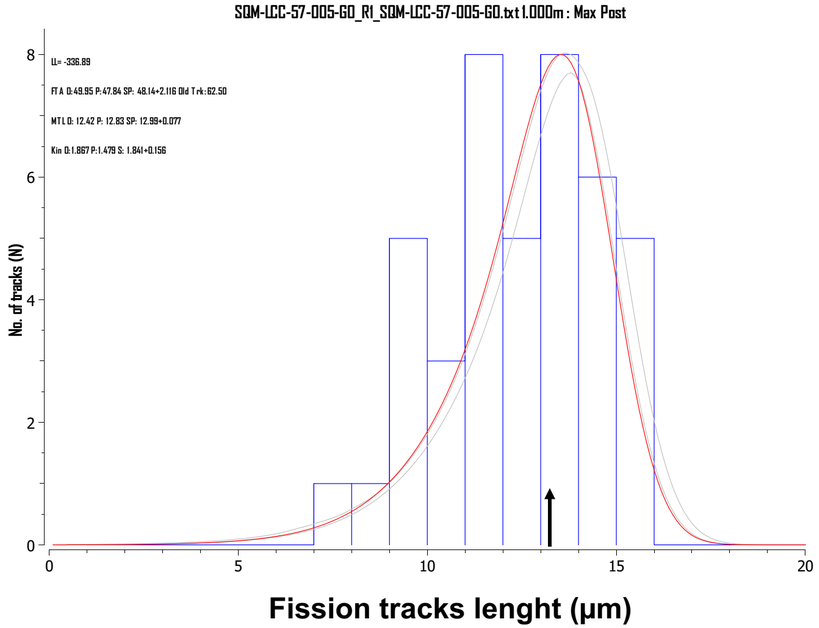
Stable isotope (SI) geochemistry from the Villeta Formation

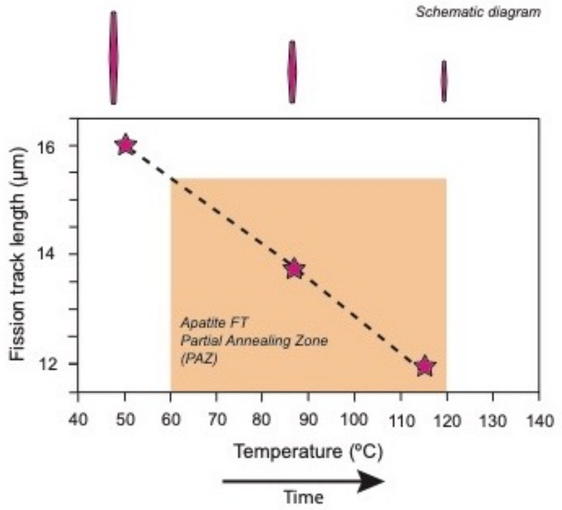


The results from stable isotopes in carbonates indicate temperatures of formation/recrystallization between ~20 and <115°C.

Thermochronology from the Villeta Formation





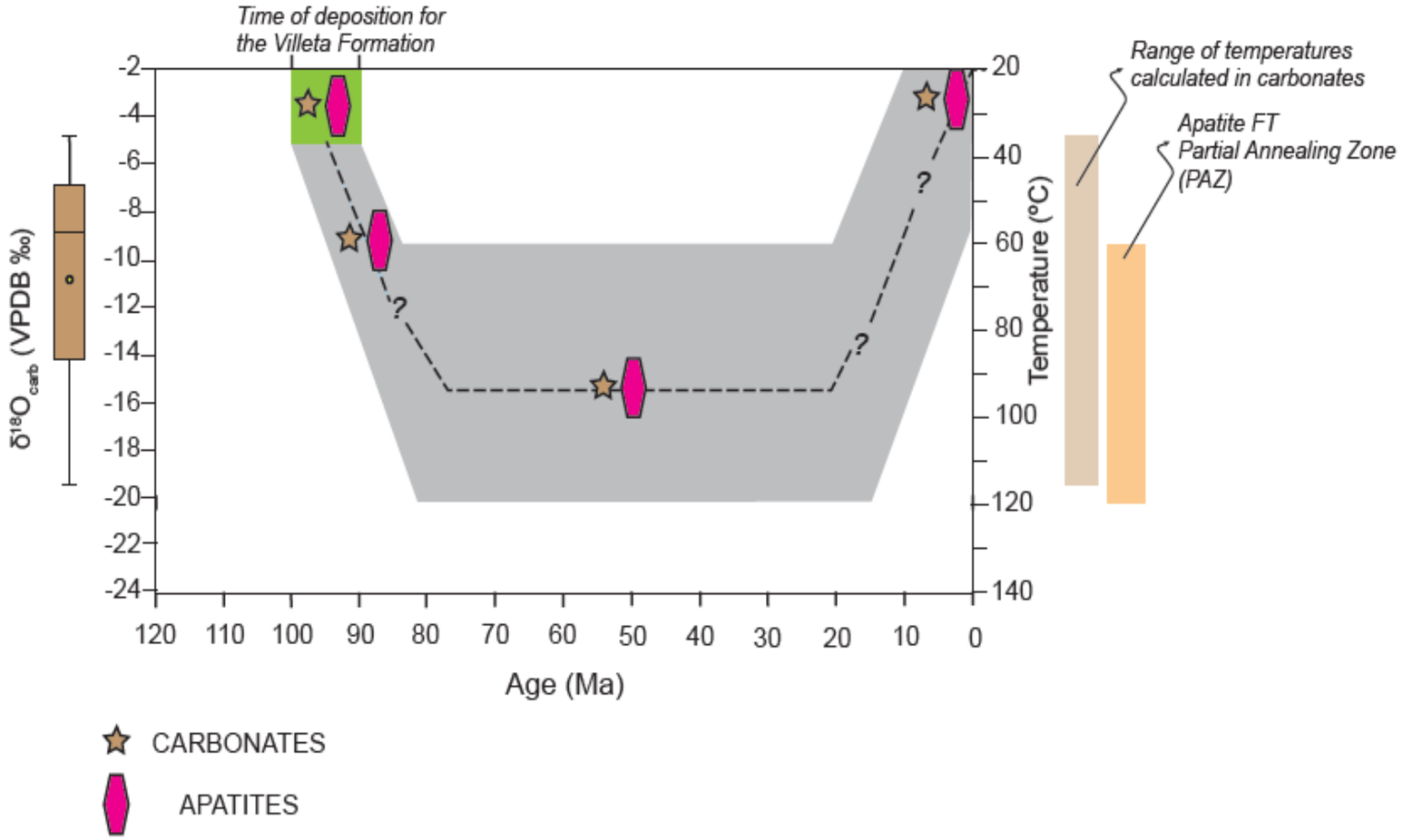


Shortening of fission tracks is a function of temperature and time

The Time VS. Temperature diagram indicates that this sample reheated within the range of temperatures proposed for the PAZ (~60-<120ºC)

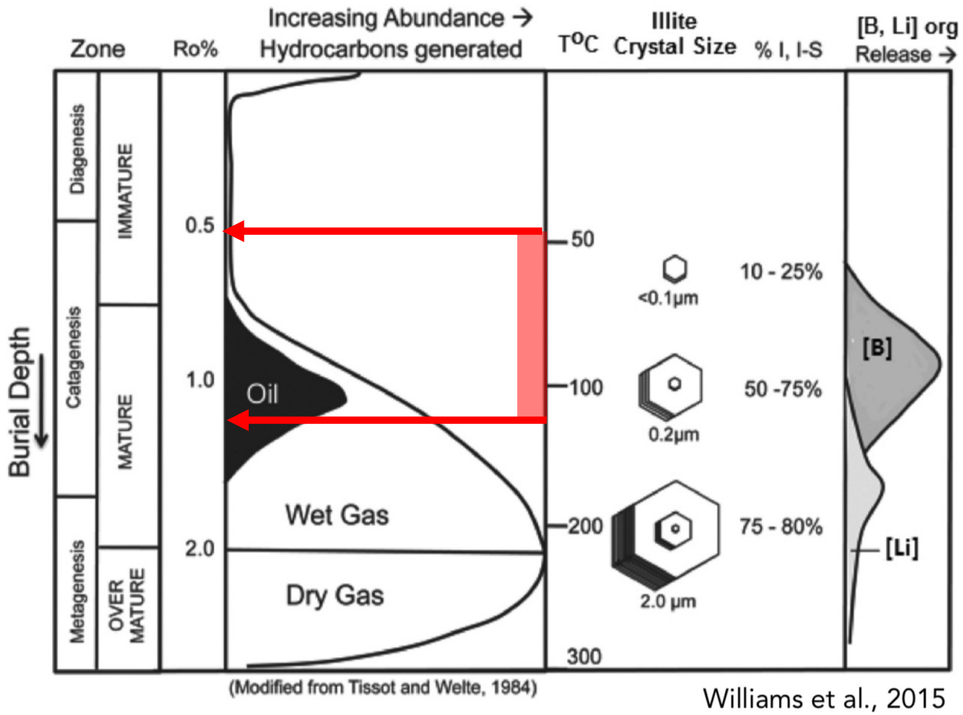
Fission tracks originally formed at ~16 µm. However, most of the tracks observed in this sample are <14µm, indicating shortening in response to reheating within the PAZ

Thermochronology and (SI) geochemistry from the Villeta Formation



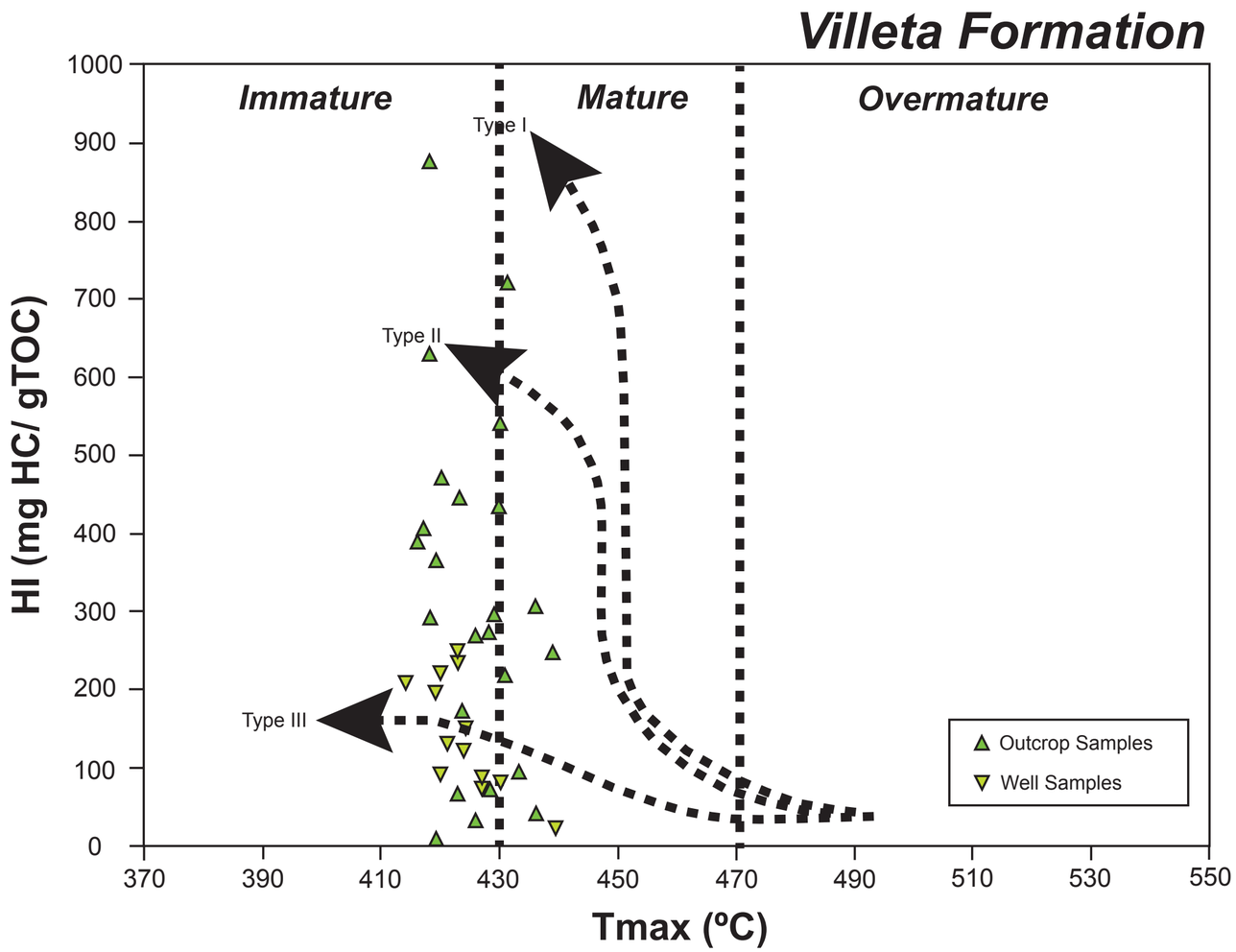
The results from stable isotopes and AFT reflect that maximum burial temperatures were <120°C.

Those temperatures are within the range of values proposed for oil generation



Williams et al., 2015

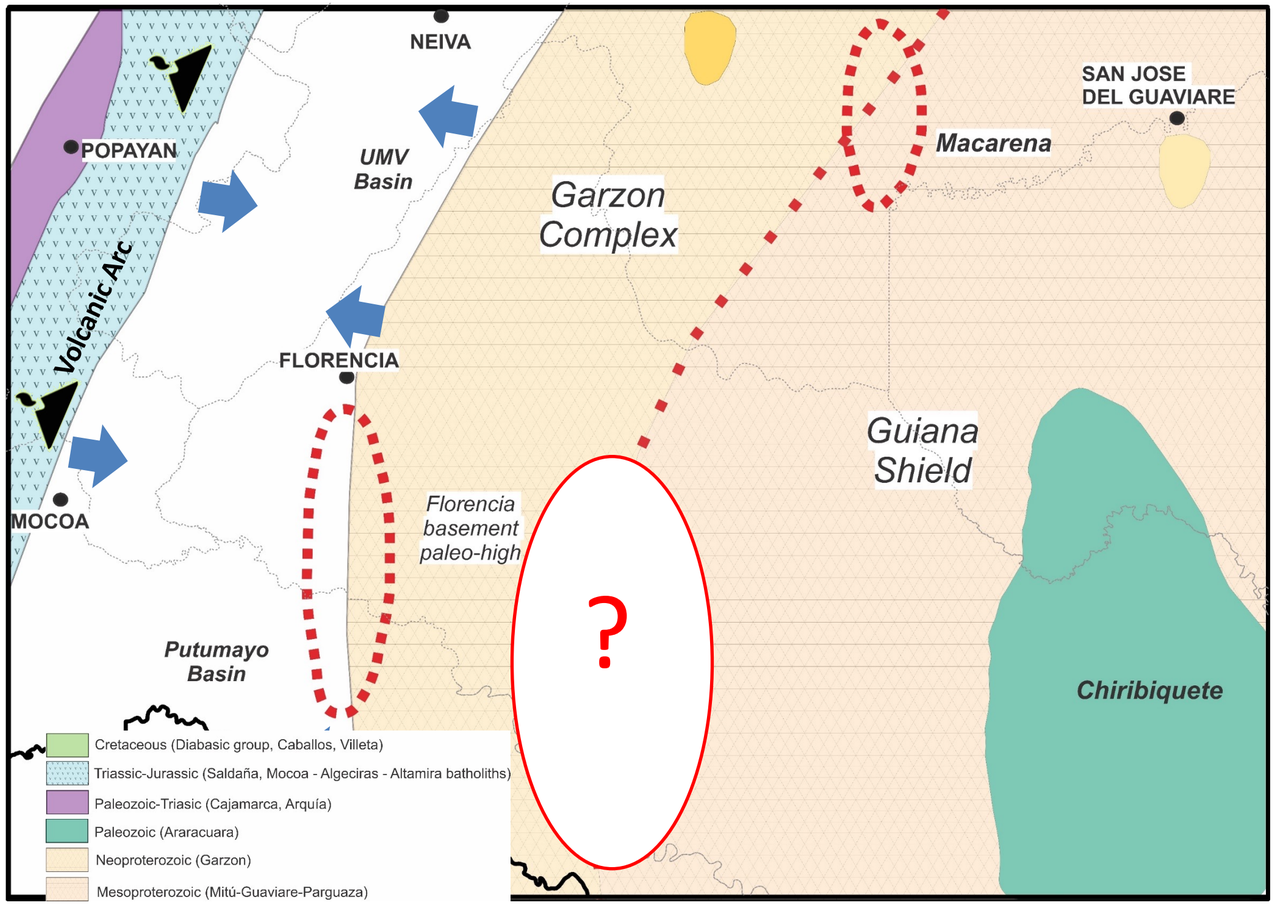
Thermal Maturity of the Villeta Formation

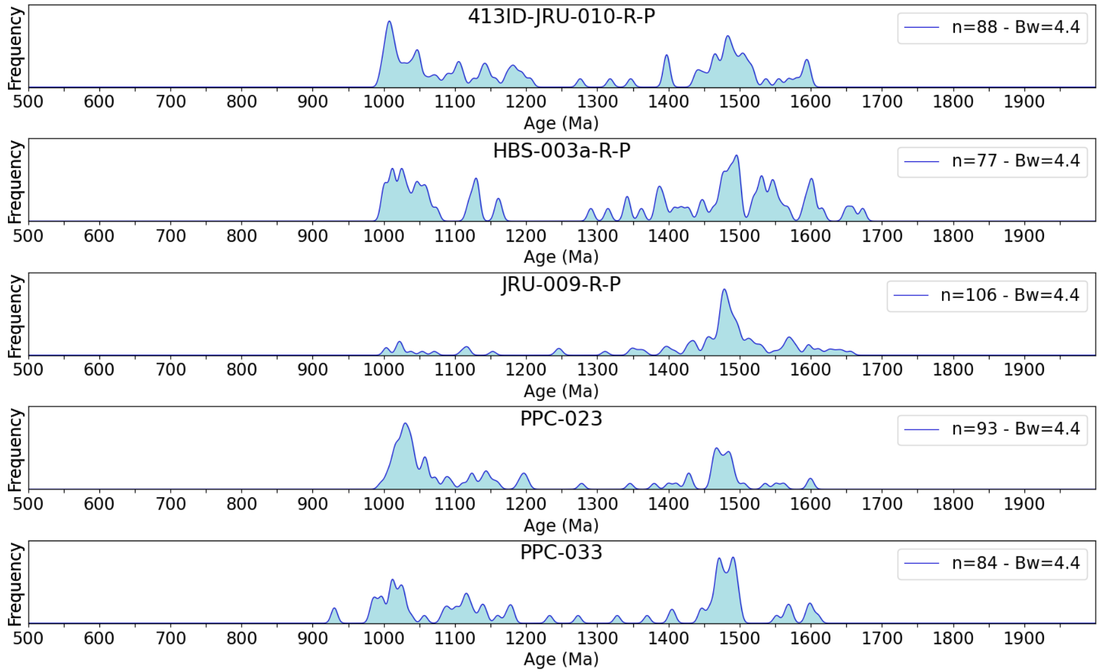


Organic geochemistry data (from those samples collected close to Florencia) also indicate that the rocks from the Villeta Formation have experienced not only moderate thermal maturity, but some of them could also be in the early stages of oil generation. It is expected that in the SW the Villeta Formation had reached greater thermal maturity, considering the greater thickness of the sedimentary deposits in this sector of the basin

Meso-Cenozoic Paleogeography

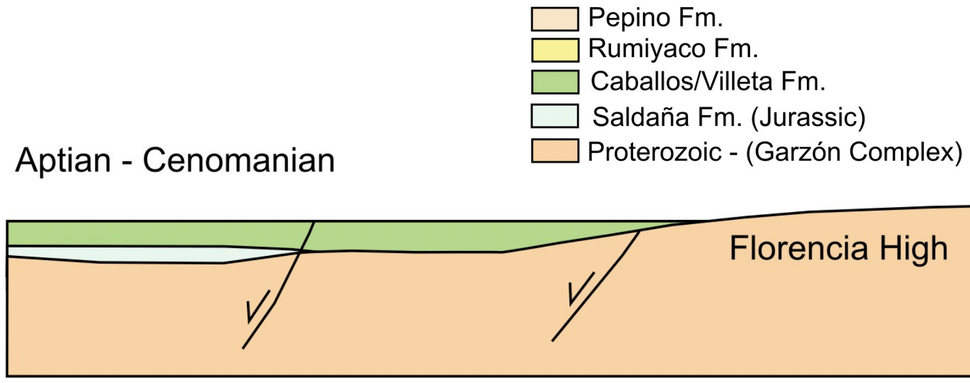
Lower Cretaceous (145- 100 Ma)





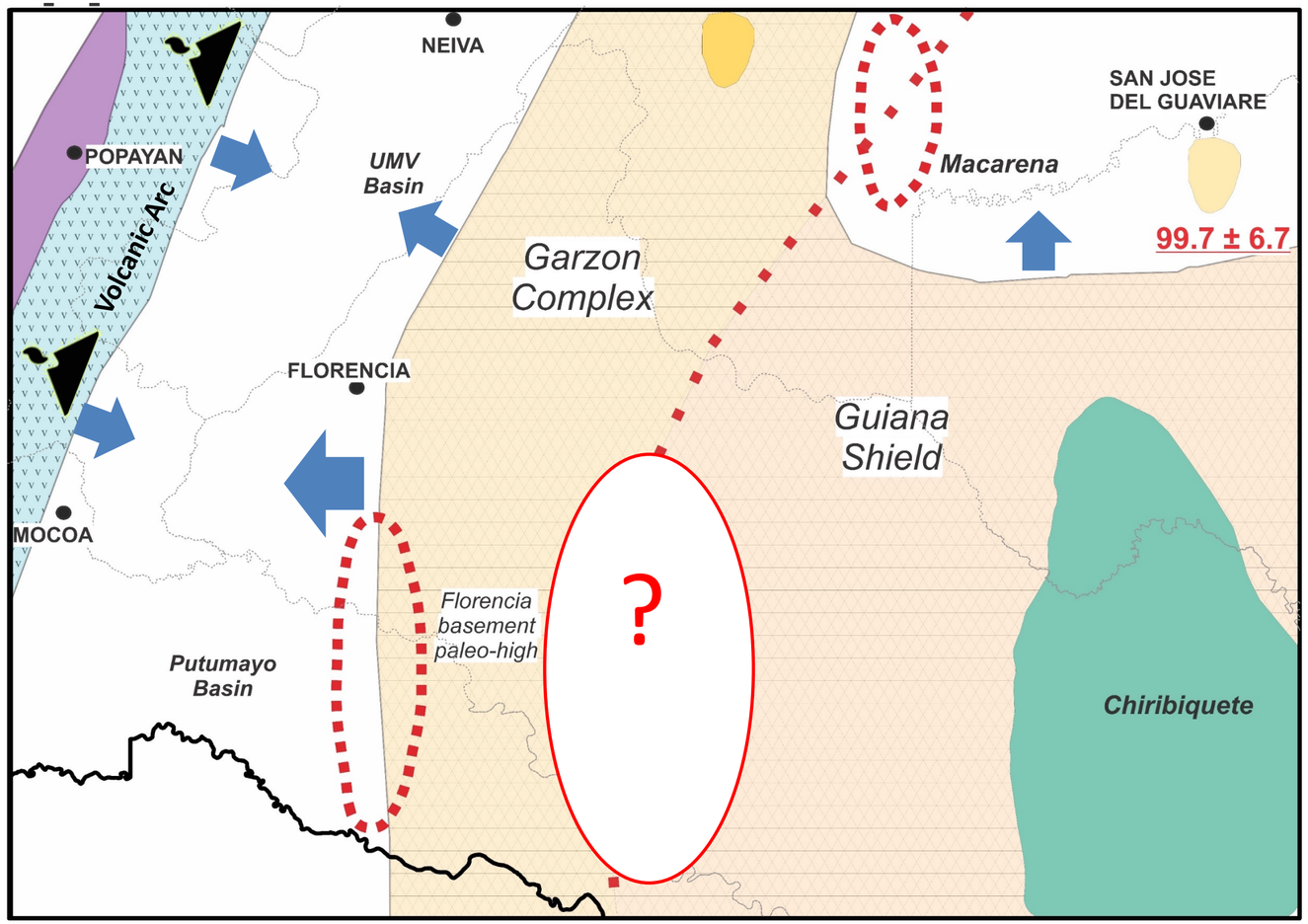
All Zr detrital ages from the Caballos Fm. Are Proterozoic

- Extensional tectonic setting
- The NW Guiana Shield have been uplifting since Jurassic sourcing sediments and the uplift of the Araracuara Fm.
- The Garzón Complex to the E and the Jurassic Volcanic Arc to the W underlie the cretaceous sediments.



- Florencia high is exposed

Upper Cretaceous (100 - 66 Ma)

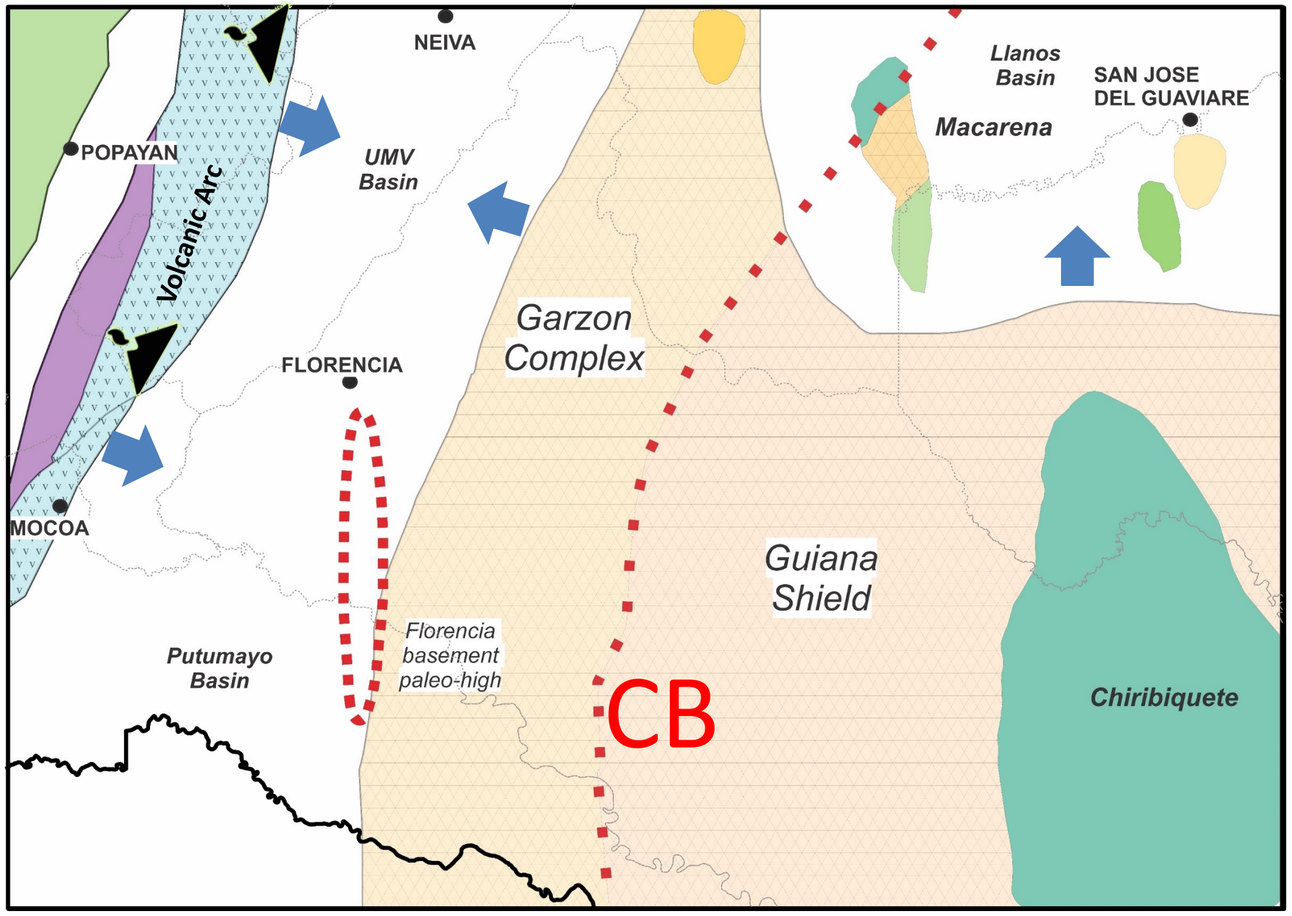


- Cretaceous (Diabasic group, Caballos, Villeta)
- Triassic-Jurassic (Saldaña, Mocoa - Algeciras - Altamira batholiths)
- Paleozoic-Triasic (Cajamarca, Arquía)
- Paleozoic (Araracuara)
- Neoproterozoic (Garzon)
- Mesoproterozoic (Mitú-Guaviare-Parguaza)

- Sedimentation of Villeta formation.
- Some positive relief of basement (Garzon and Saldaña) was present
- Florencia paleo-high basement was exposed
- The Nepheline Syenite is outcropping as source of Ediacaran (600Ma) zircons ***(see Villeta Provenance)***.
- There are not documented Albian-Coniacian deposits to the NE of Florencia High (Caballos and Villeta)

- Cretaceous sediments could source the Caqueta Basin form the south?

Paleocene (66 - 56 Ma)

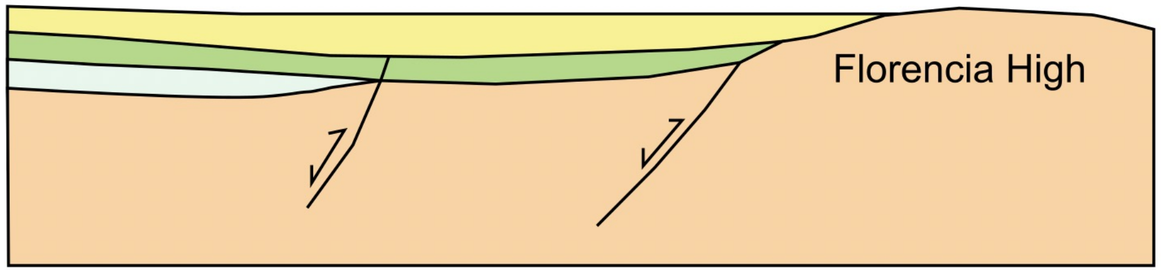


- Cenozoic (Rumiyaco, Pepino, Orteguaza)
- Cretaceous (Diabasic group, Caballos, Villeta)
- Triassic-Jurassic (Saldaña, Mocoa - Algeciras - Altamira batholiths)
- Paleozoic-Triasic (Cajamarca, Arquía)
- Paleozoic (Araracuara)
- Neoproterozoic (Garzon)
- Mesoproterozoic (Mitú-Guaviare-Parguaza)

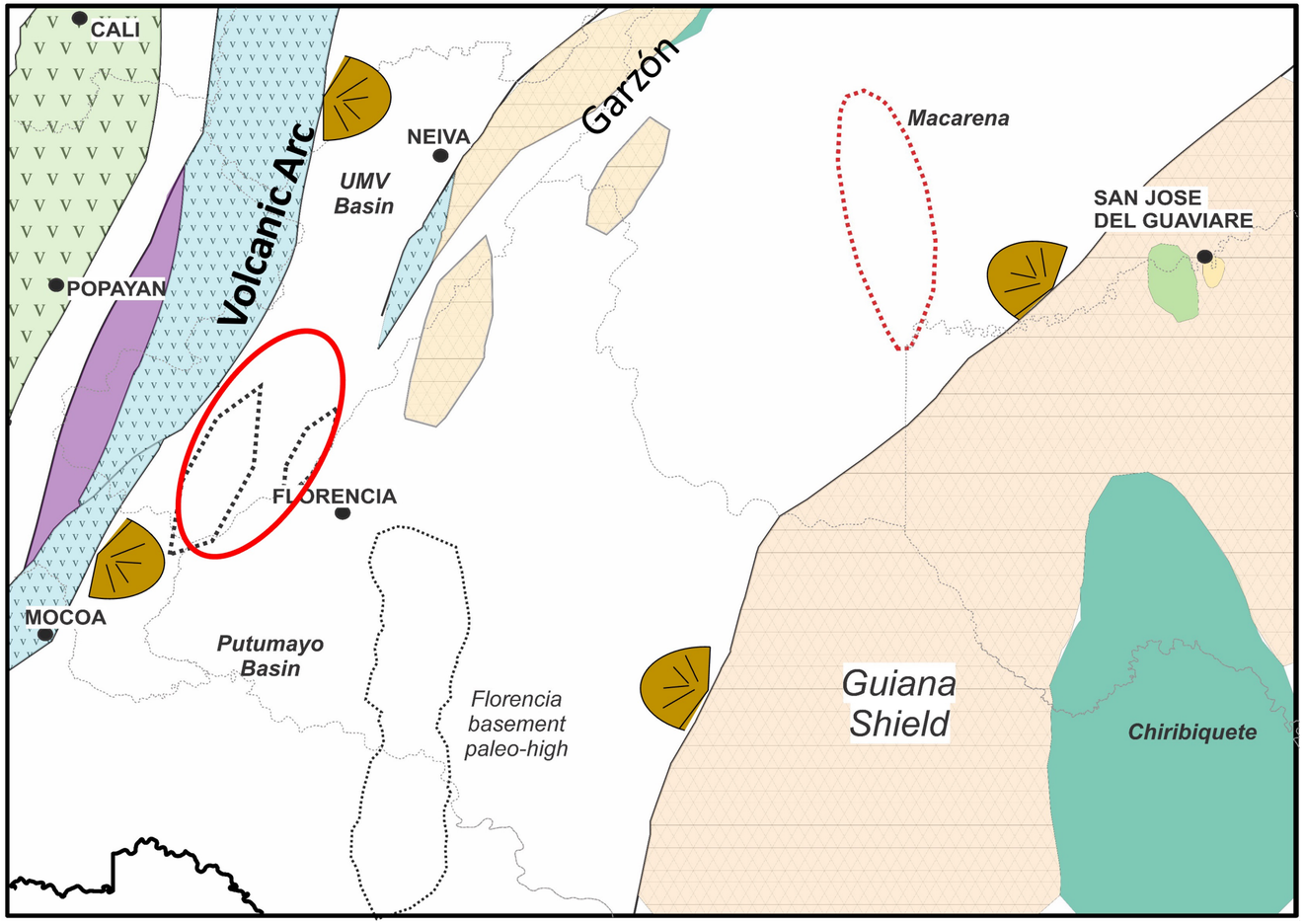
- Sedimentation of Rumiyaco Fm.
- Some positive relief of basement (Garzon and Saldaña) are exposed
- Florencia High still divided the Putumayo basin from Caqueta Basin (CB)
- To the NE of Florencia paleohigh Paleocene-Eocene deposits are documented at the Macarena Range

- Pepino Fm.
- Rumiyaco Fm.
- Caballos/Villeta Fm.
- Saldaña Fm. (Jurassic)
- Proterozoic - (Garzón Complex)

Maastrichtian - Paleocene



Eocene (56 - 34 Ma)

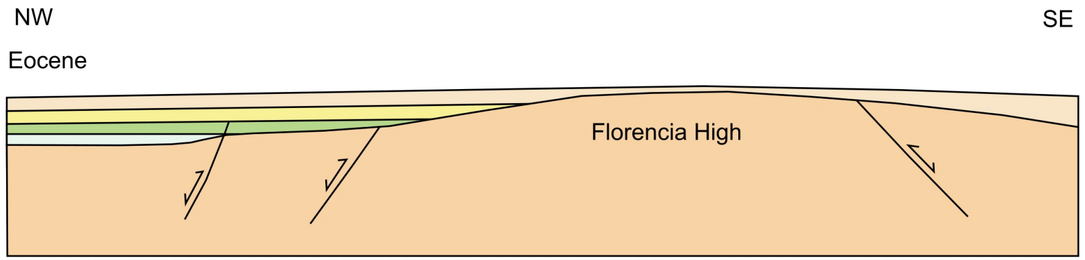


- Cenozoic (Rumiyaco, Pepino, Orteguaza)
- Cretaceous (Diabasic group, Caballos, Villeta)
- Triassic-Jurassic (Saldaña, Mocoa - Algeciras - Altamira batholiths)
- Paleozoic-Triasic (Cajamarca, Arquía)
- Paleozoic (Araracuara)
- Neoproterozoic (Garzon)
- Mesoproterozoic (Mitú-Guaviare-Parguaza)

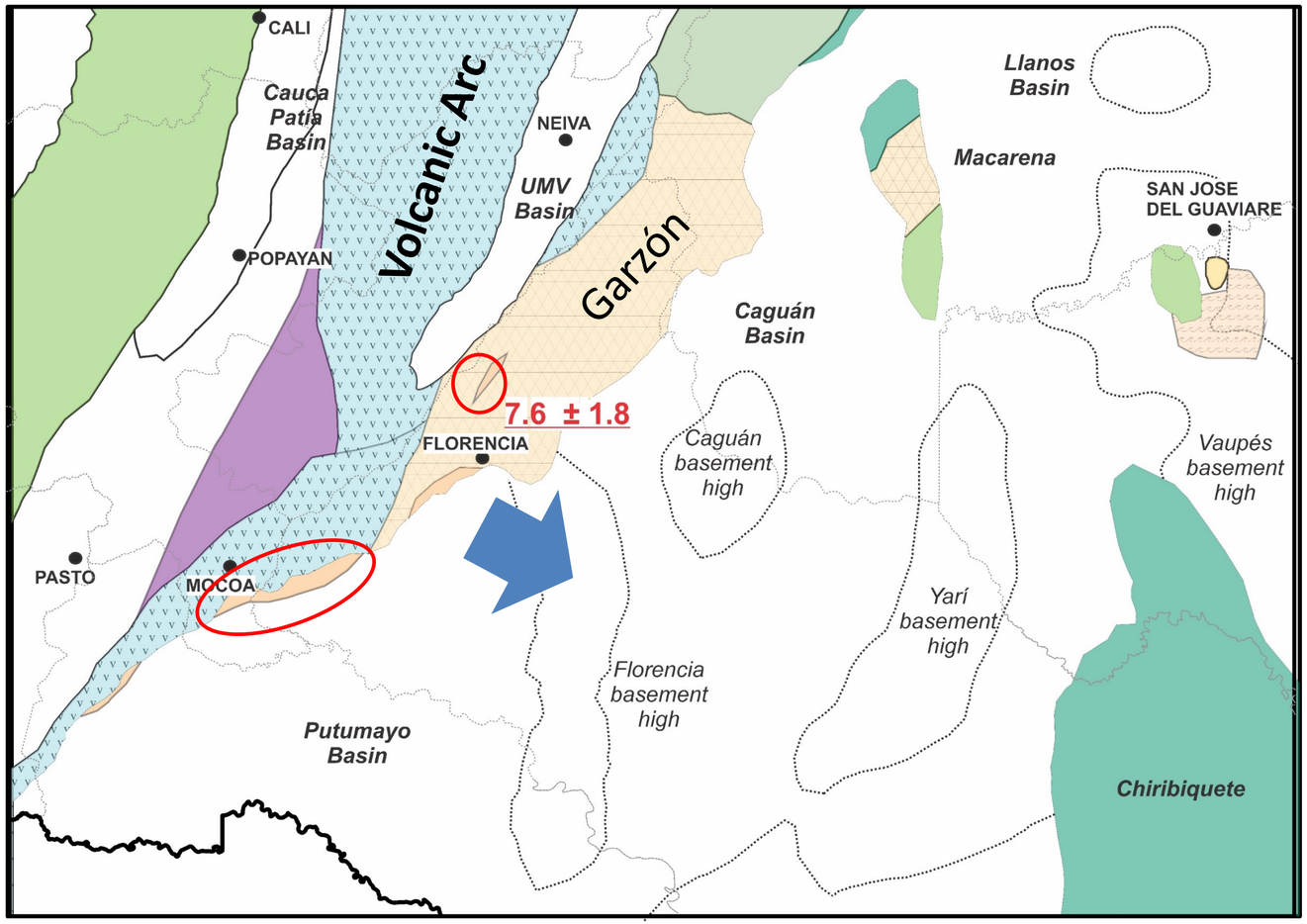
- Most of the Garzon massif has been buried by sediments
- Sedimentation of Pepino Fm under alluvial fan an alluvial channels.
- Macarena has been buried (***see AFT***)
- It is likely that local depocenters reached temperatures of oil generation in local pods in the foredeep and piggy-back basins.

- Piggy-Back Basins likely related to local basement highs

- Pepino Fm.
- Rumiyaco Fm.
- Caballos/Villeta Fm.
- Saldaña Fm. (Jurassic)
- Proterozoic - (Garzón Complex)



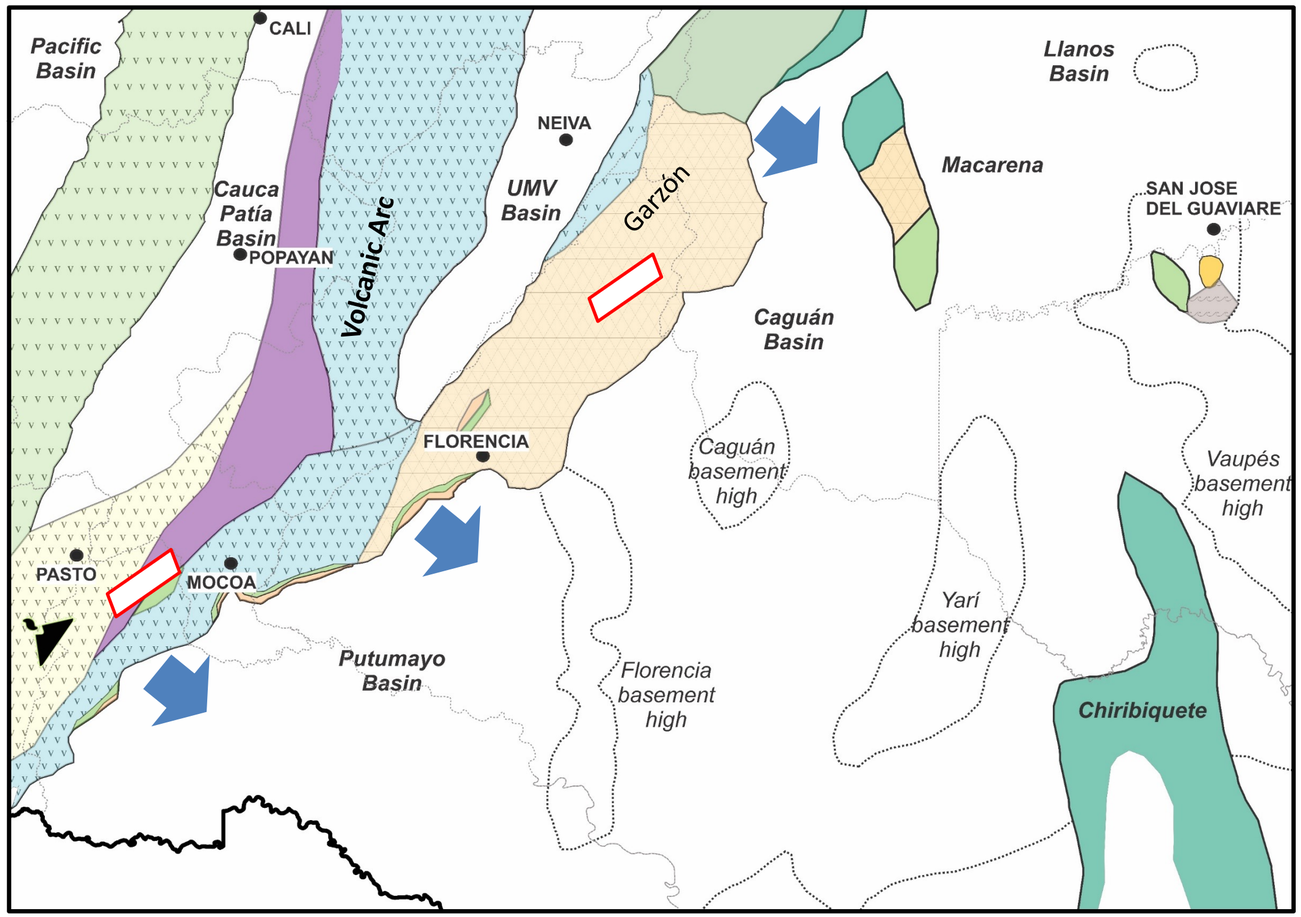
Oligocene-Miocene (34 – 5.3 Ma)



Cenozoic (Rumiyaco, Pepino, Orteguaza)
Cretaceous (Diabasic group, Caballos, Villeta)
Triassic-Jurassic (Saldaña, Mocoa - Algeciras - Altamira batholiths)
Paleozoic-Triassic (Cajamarca, Arquía)
Paleozoic (Araracuara)
Neoproterozoic (Garzon)
Mesoproterozoic (Mitú-Guaviare-Parguaza)

- Major onset of basement unroofing documented along the northern Andes (AFT)
- Protracted Compressive setting with Pepino Fm. Exhumation into the deformation front
- Some stratigraphic sequences have been isolated into the Garzón massif due major erosion of the sedimentary cover and exhumation of the Garzón massif
- UMV and Putumayo basins are now compartimentalized, reservoir conections are now gone

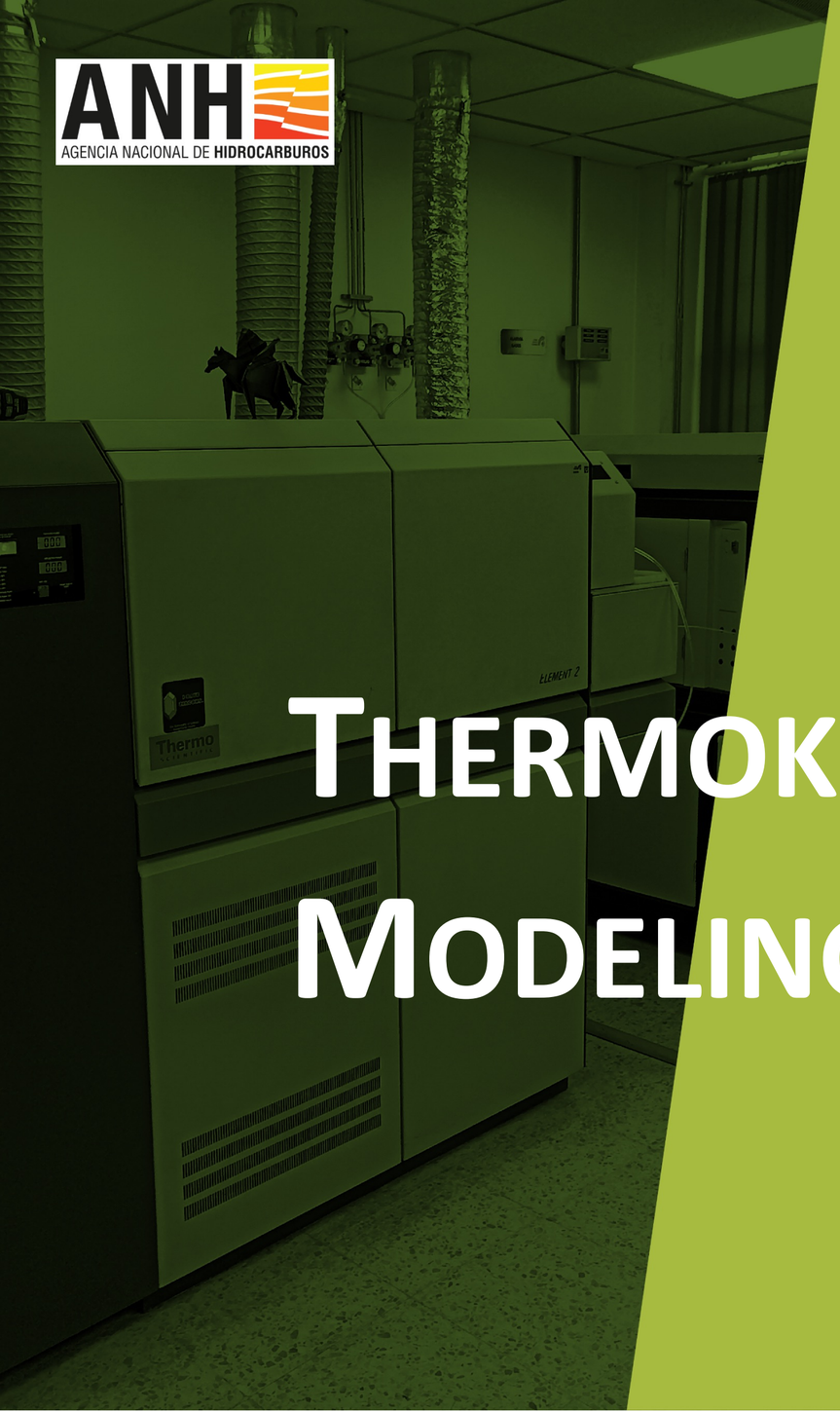
Pliocene (5.3 – 2.5 Ma)



Cenozoic (Rumiyaco, Pepino, Orteguaza)
Cretaceous (Diabasic group, Caballos, Villeta)
Triassic-Jurassic (Saldaña, Mocoa - Algeciras - Altamira batholiths)
Paleozoic-Triassic (Cajamarca, Arquía)
Paleozoic (Araracuara)
Neoproterozoic (Garzon)
Mesoproterozoic (Mitú-Guaviare-Parguaza)

- Paroxism of the Andean Orogeny defines last uplifting pase
- Garzón Uplift
- Basement highs are visible on the gravimetry at their current configuration
- Extended sedimentary cover (alluvial) due erosion of exhumed basement
- Cenozoic vulcanism on the central cordillera

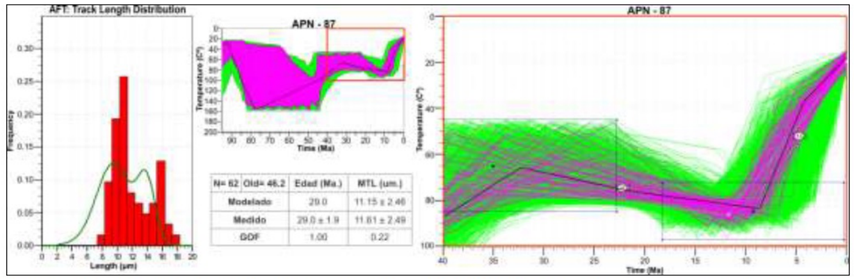
- Strike-slip tectonics induce the formation of local Pull-apart basins with a rhomboedral shape (Sibundoy-Balsillas)



Thermokinematic Modeling

Kinematic Evolution

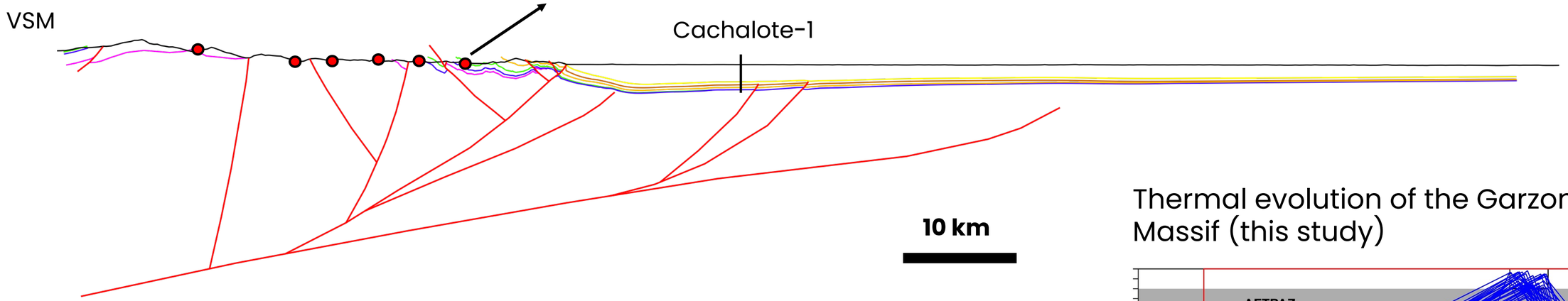
Present-day

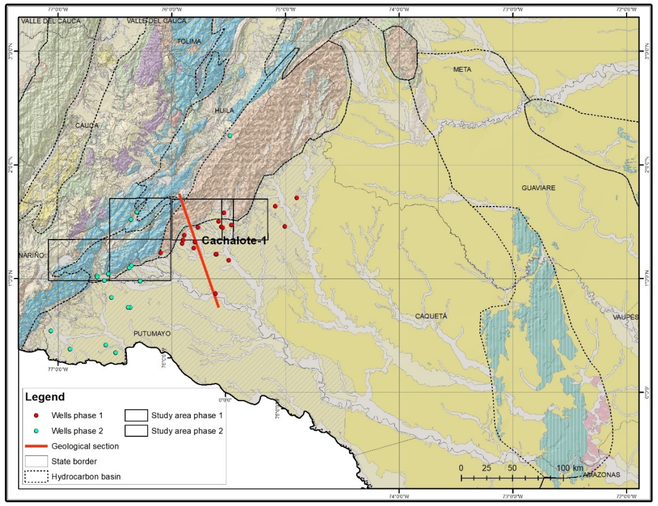


Thermal evolution documented in Ramirez (2016)

NW **SE**

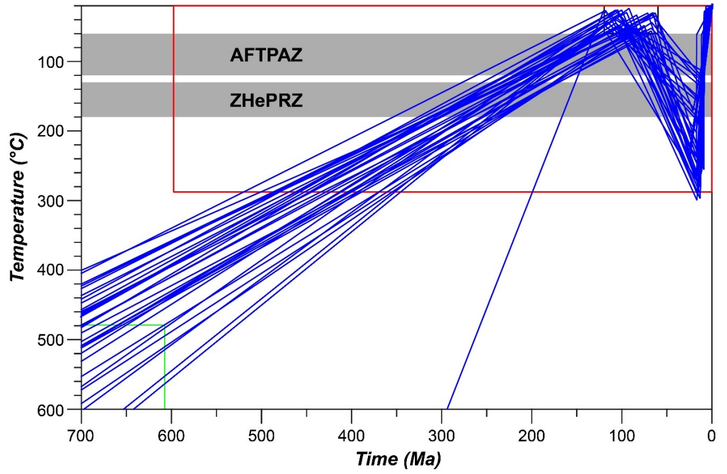
Samples with thermal evolution



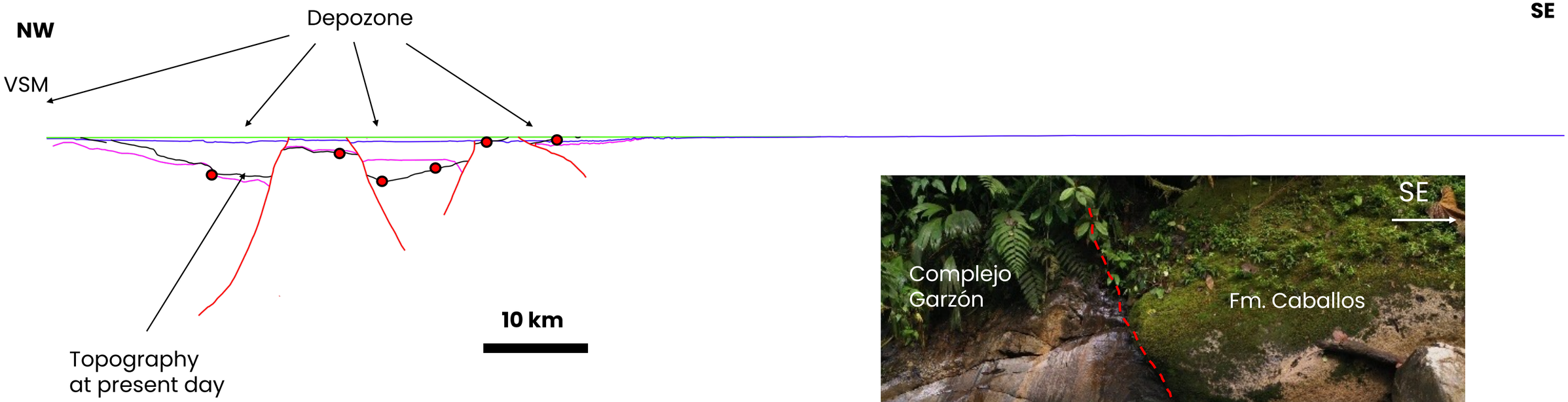


Integration of surface and subsurface observations and geochemical analysis across the Pantera-1 (VSM) to Cachalote-1 wells section.

Thermal evolution of the Garzon Massif (this study)



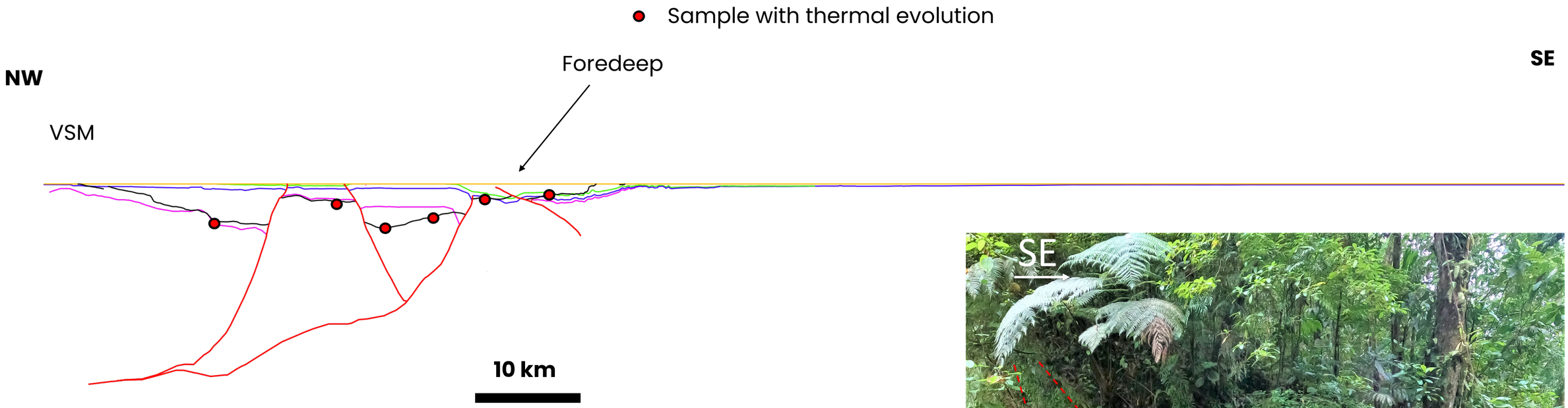
Upper Cretaceous



Rifting stage: sedimentation on inherited grabens developed during the Jurassic age. Existence of sub-basins between the VSM and the present-day fore-bulge.

The Cretaceous exposure of the Garzón massif is documented by a regional unconformity

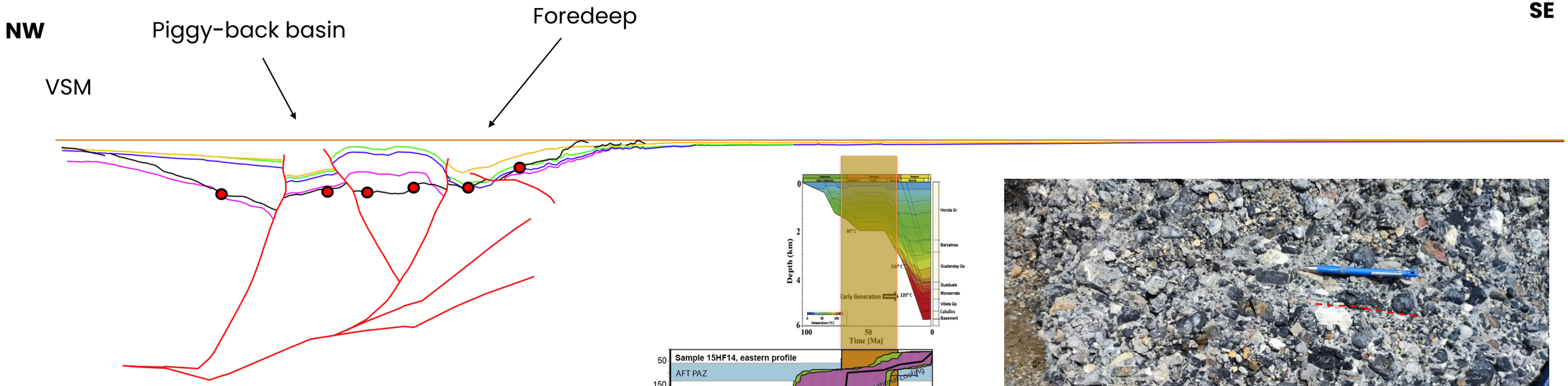
Paleocene



Basin inversion: Generation of a foredeep.

During the Paleocene tectonic activity is evidenced by growth strata (Rumiyaco Fm.)

Eocene-Oligocene



Foreland basin: Maximum accumulation in the foredeep and generation of a piggy-back basin.

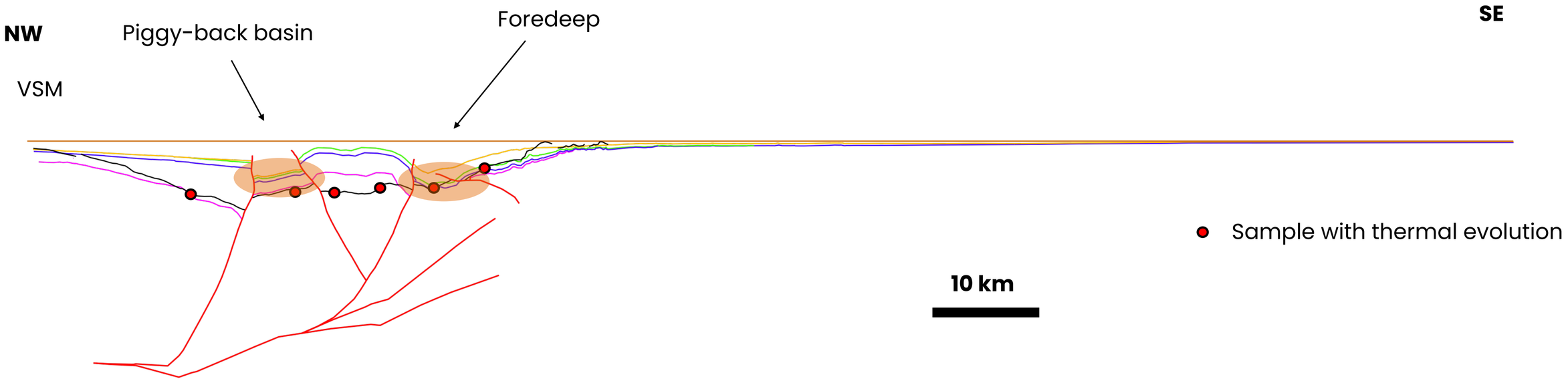
Chert rich Pepino Fm.

Thermal history of the UMV

Villamizar et al., 2021

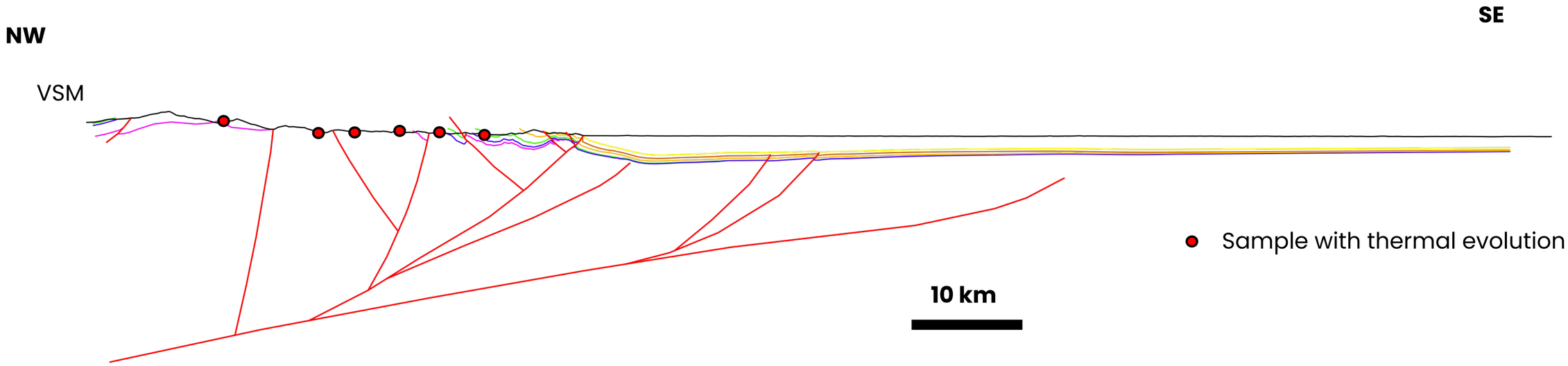
Eocene clastic syntectonic sediments were deposited in both flanks of the Garzón Massif, composed by Chert indicating onset of exhumation of the Central Cordillera.

Eocene-Oligocene



Foreland basin: Maximum accumulation in the foredeep and generation of a piggy-back basin. Petroleum generation in these basins (paleo-kitchens).

Present-day



Oligocene to present-day: Erosion of the paleo-kitchens.

SUMMARY

Findings

- All the surface, subsurface, geo-thermochronological, and isotopic data strongly indicate that the crystalline basement has experienced multiple episodes of exhumation during the Phanerozoic, always accompanied by thermal subsidence and syntectonic sedimentation, during the Jurassic, Cretaceous, and Cenozoic.

- The Garzón Massif and the Macarena Range are metamorphic nuclei, the first related to Oaxaca and the second related to Amazonia, given their structural configuration their exhumation histories are completely different and had influenced the distribution of source and reservoir rocks and the evolution of oil migration paths.

- Thermochronological data show that the Cagüán-Putumayo and Llanos basins were connected until the Oligocene, since then they have been independent basins.

- The seismic stratigraphic terminations for different formations (Cretaceous and Cenozoic) against the Florencia High represent good potential traps (stratigraphic and combined traps) that are present along both sides of the Paleo high.

Findings

- The potential reservoirs in this basin are associated with structural traps in high-angle basement faults in the foreland, with stratigraphic traps associated with wedging in the direction of the regional basement highs (Florencia, Macarena, Vaupés), and finally with “tar -mats”.

- The potential source rocks in the area near the Eastern Cordillera foothills become more thermally mature towards the SW, furthermore Isotopic and thermochronologic data reveal that they could reach the oil-generation window during the Eocene-Oligocene times, and afterwards such paleo-kitchens were partially exhumed.

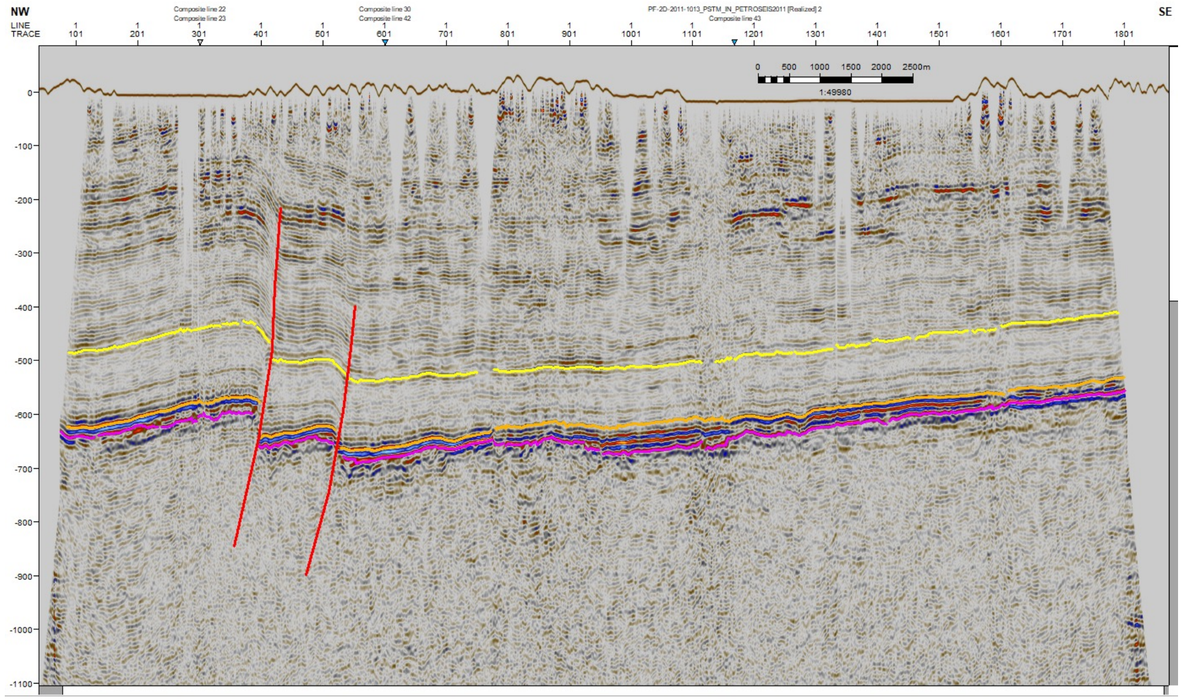
- The analyzed samples located in the northern part of the Putumayo basin show that the Caballos and Villeta formations contain a mixture of type I & II kerogen originated from marine organic matter, which presents good source-rock qualities (TOC > 1%) and reached the necessary depth and temperatures (for instance the thermal maturity (Tmax > 430°C) in the piggyback basin and foredeep) to be in the early stages of the oil generation window in the Eocene.

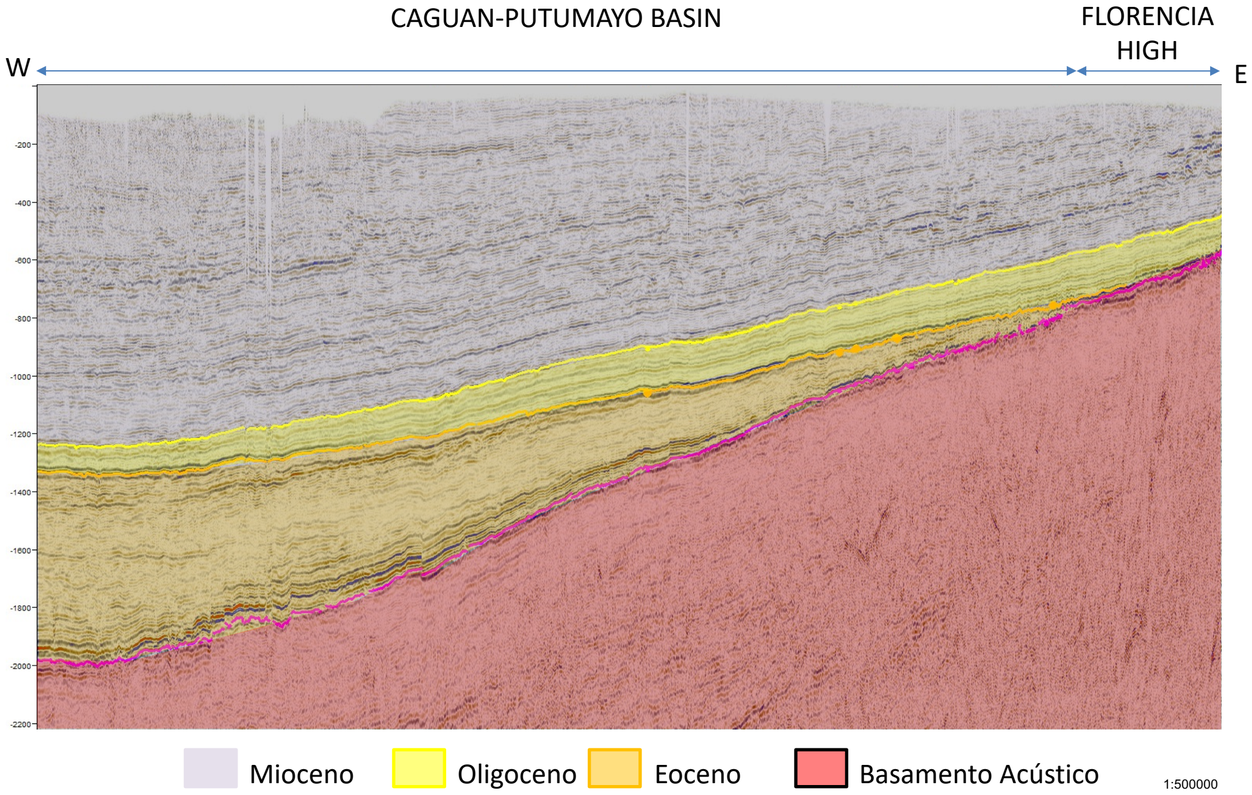
- Although the former data indicates that the reservoirs were likely fed from local paleo-kitchens, this does not rule out that other oil pods in the UMV and south Putumayo couldn’t be involved in sourcing hydrocarbons to the basin.

- The understanding of the structural framework of the Caguan and Putumayo basin allows us to differentiate the prospective corridors of the Cenozoic, Cretaceous and pre-Cretaceous structures and plays.

- Stratigraphic plays as Capela resemble inverted half-graben structures as those documented in Ecuador ITT, furthermore Capella and ITT fields are located within the same structural domain, the big question is if such oil systems are related?

Stratigraphic and structural potential oil accumulations



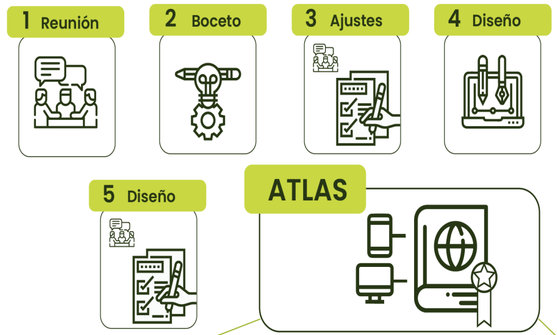


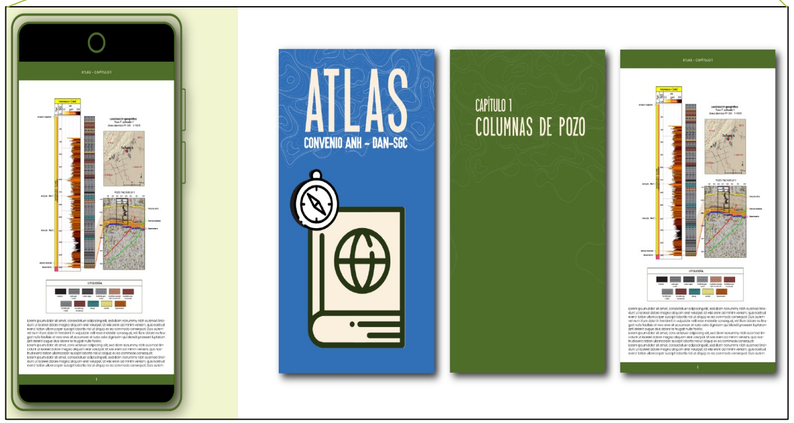
Opportunities for structural entrapment exist in high-angle basement faults and in backthrusts involving thin-skin deformation.

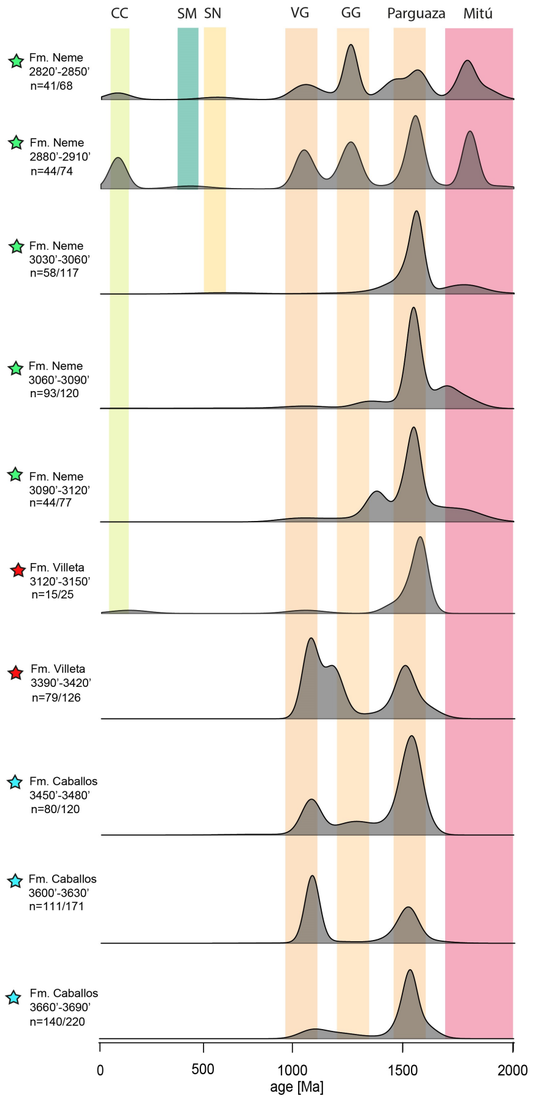
The Florencia High is also interesting due to the possibility of post-Eocene stratigraphic entrapments after the Macarena uplift.

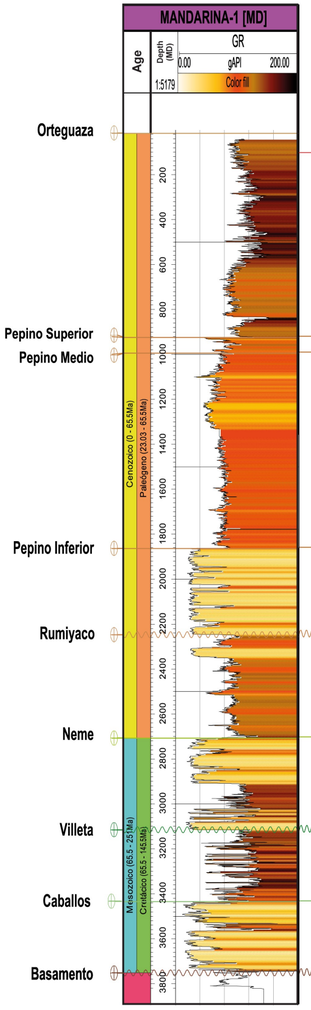
Integrated Atlas

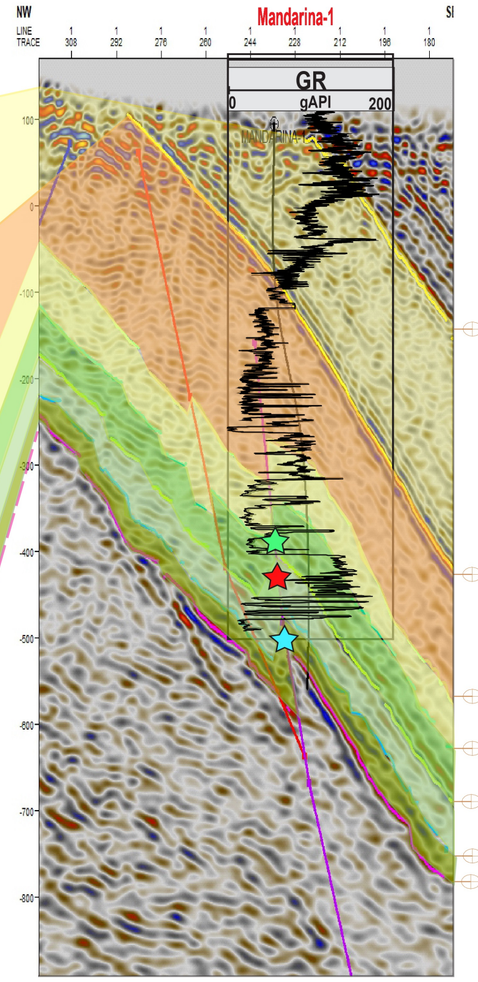
Design Seismic-Chrono-Stratigraphic ATLAS DAN-ANH

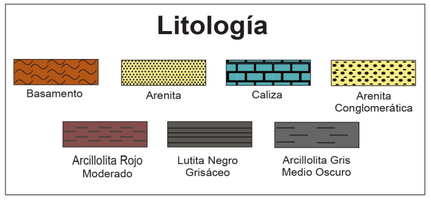












CC: Central Cordillera, SM: Santander Massif, SN: Syenite Nepheline, VG: Vergel Granulite, GG: Guapoton Gneiss

Acknowledgements

Colombian Geological Survey

- Hernan Olaya Dávila — DAN Director — Humberto Andrés Fuenzalida DTH Director
- Mary Luz Peña Urueña — Project Manager

ANH

- Liliana Zuleta — Technical Vicepresident
- Jose Miguel de Armas — Knowledge Manager
- Arlex Gutierrez — Technical Supervisor
- Hugo Buitrago — Technical Supervisor

SGC-DAN Staff

- Jimmy Muñoz Carolina Jimenez — U-Pb Geochronology Laboratory
- David Contreras — SEM Advanced Microscopy Laboratory
- Maribel Moreno Andrea Rocha — Solid Stable Isotope Analysis Laboratory
- Andres Porras — Liquid Stable isotope Analysis Laboratory
- Petrochron project Staff

UPTC

- Prof. Mauricio Bermudez & staff Thermochronology Laboratory

Communities and local authotities from the Caqueta, Meta, Guaviare, Putumayo, Huila and Amazonas department

CONOCIMIENTO CIENTÍFICO Y COMUNIDAD

https://www.sgc.gov.co/