Reconstruction of the evolution and infill of the Pliocene to early Pleistocene Tubará-Juan de Acosta Syncline, northern San Jacinto fold belt, NW Colombia & implications for hydrocarbons.

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1. *Hocol S.A.*
2. *ATG Ltda.*
3. *Génesis*
4. *University of Arizona*
5. *Stratos*
6. *Paleoflora*
7. *ANH*

Arroyo Saco section, photo by JA. Mora, 2021

Agenda

1. Introduction: Objective, study area and geological framework
2. Methodology & database
3. Seismic interpretation & mapping
4. Field geology and core descriptions
5. Depositional model & paleogeography
6. Conclusions & implications for hydrocarbons

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Introduction-Hocol assets, values and purpose

- Hocol is a company of the Ecopetrol Group, focused on exploration and production of gas and light oil in the Upper Magdalena, Central Llanos, Lower Magdalena, Sinú-San Jacinto and Guajira basins (onshore).

- Hocol was born almost 66 years ago in the Upper Magdalena Valley and has been owned by several companies (Intercol-Tennessee, Petrocol, Colbras, Tenneco, Houston Oil Colombia, Shell, Nimir, Maurel et Prom and Ecopetrol since 2010).

- Hocol´s corporate values are:

PIONERO

Somos Pioneros siendo innovadores: cuando nos adaptamos al entorno e impactamos con ideas creativas, nos desafiamos y nos reinventamos para lograr resultados extraordinarios.

HUMANO

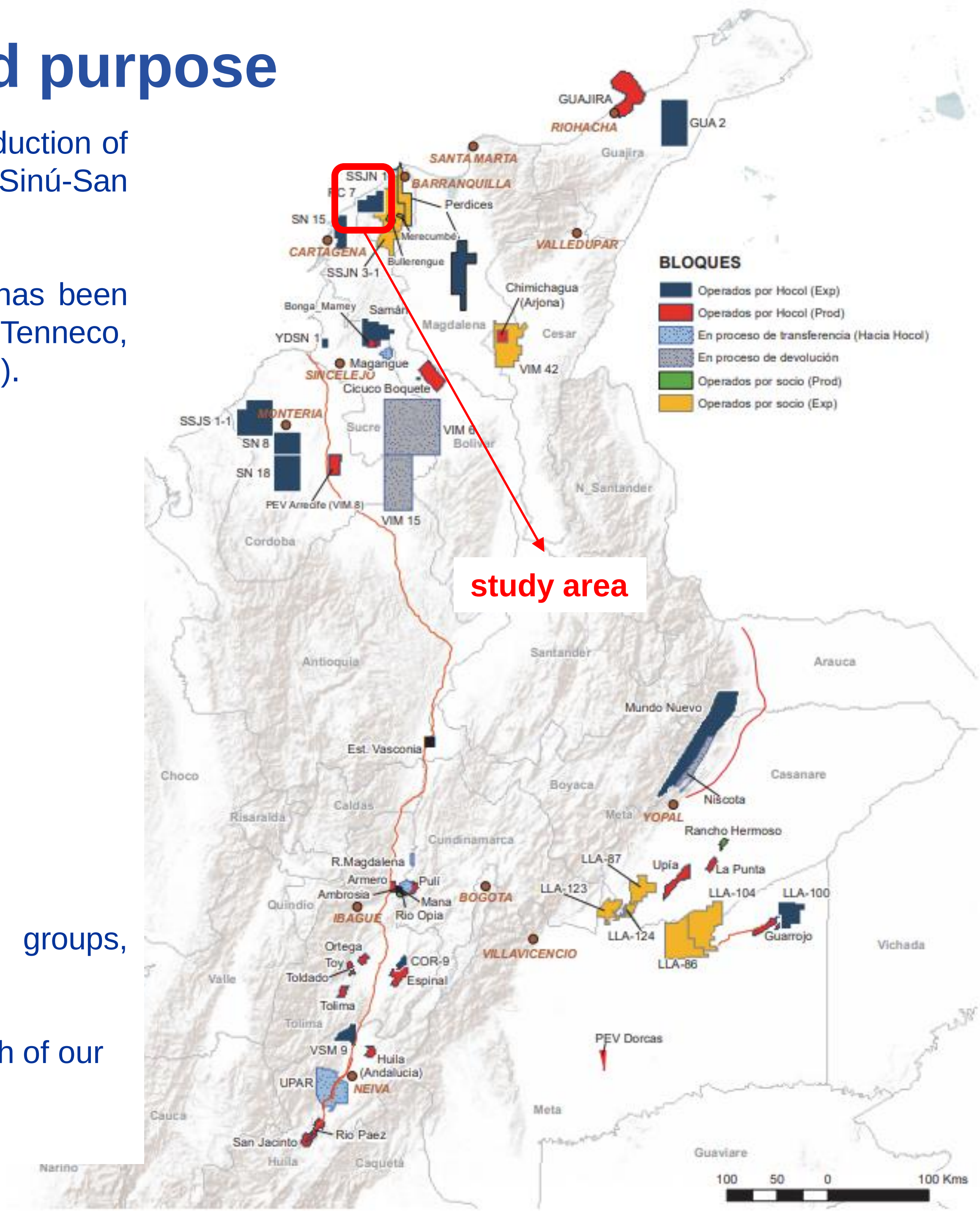
Somos Humanos siendo empáticos: cuando nos interesamos genuinamente por los demás, entendiendo y respetando sus necesidades y motivaciones para lograr el beneficio común, reconociendo y cuidando el impacto de mis acciones.

CONFIABLE

Somos Confiables cuando: cumplimos nuestra palabra y demostramos tenacidad con los compromisos y las metas a través de la autogestión, generando credibilidad.

- At Hocol we promote respect for life, the environment, the interest groups, transparency, democracy and sustainability.

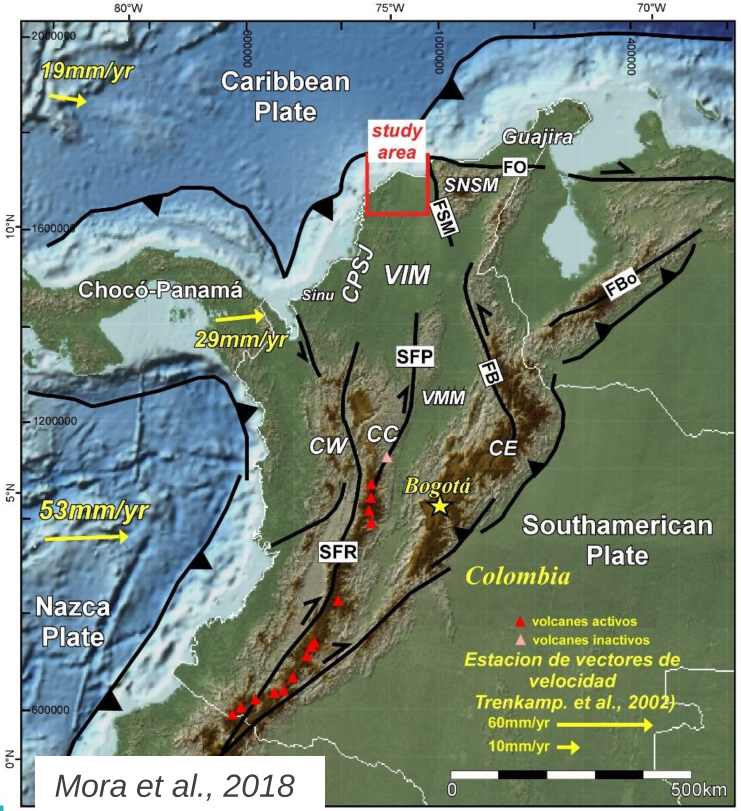
- Our purpose is “Life first”, hence we constantly prioritize the integrity and health of our collaborators, allies and communities.



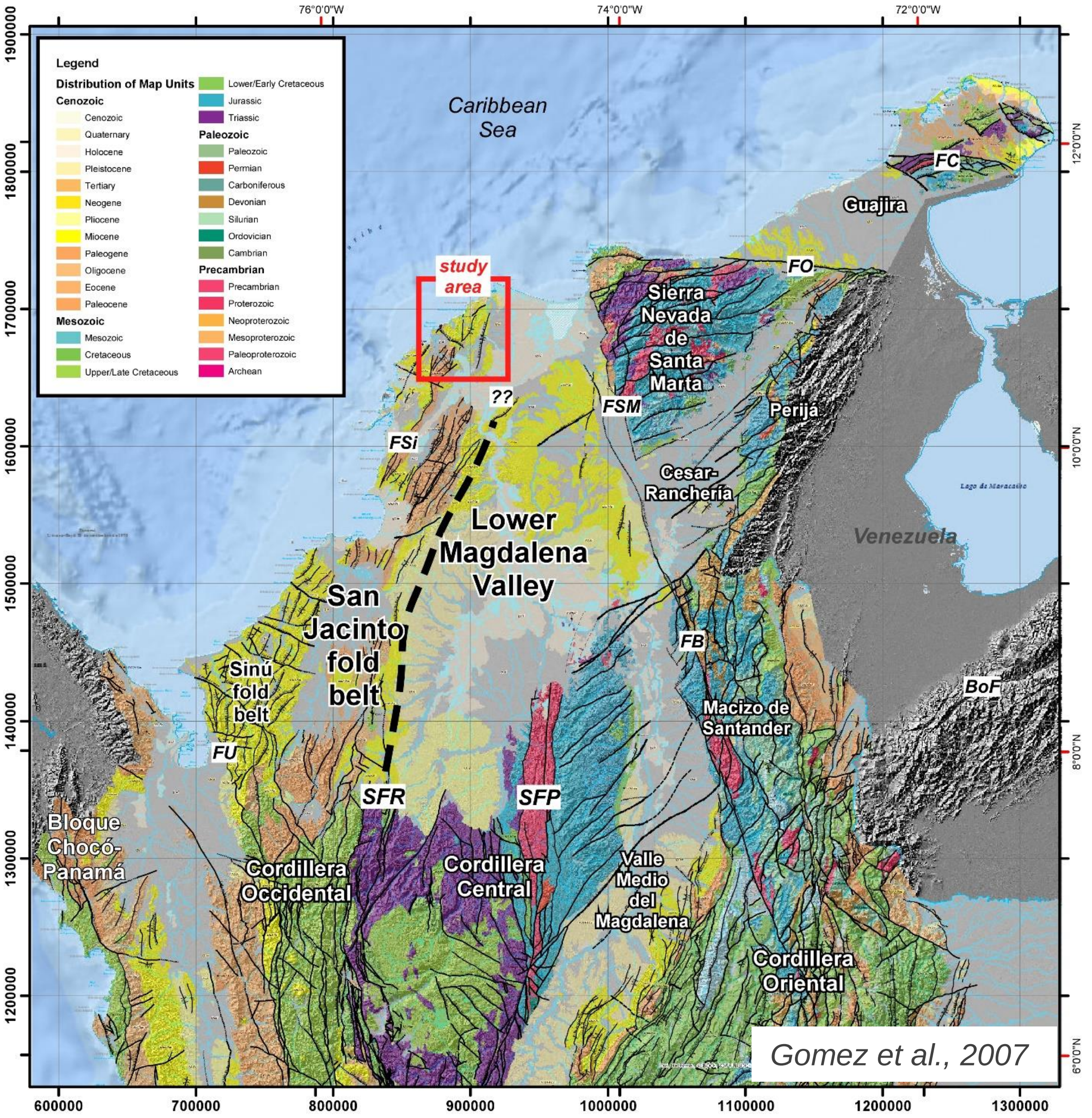
Introduction

Objective: Reconstruct the evolution and infill of the Tubará-Juan de Acosta syncline (TJAS) through the integration of different types of geological and geophysical information.

Location: northernmost San jacinto fold belt
(area where we did a pre-Conference field trip in the last AAPG ICE)

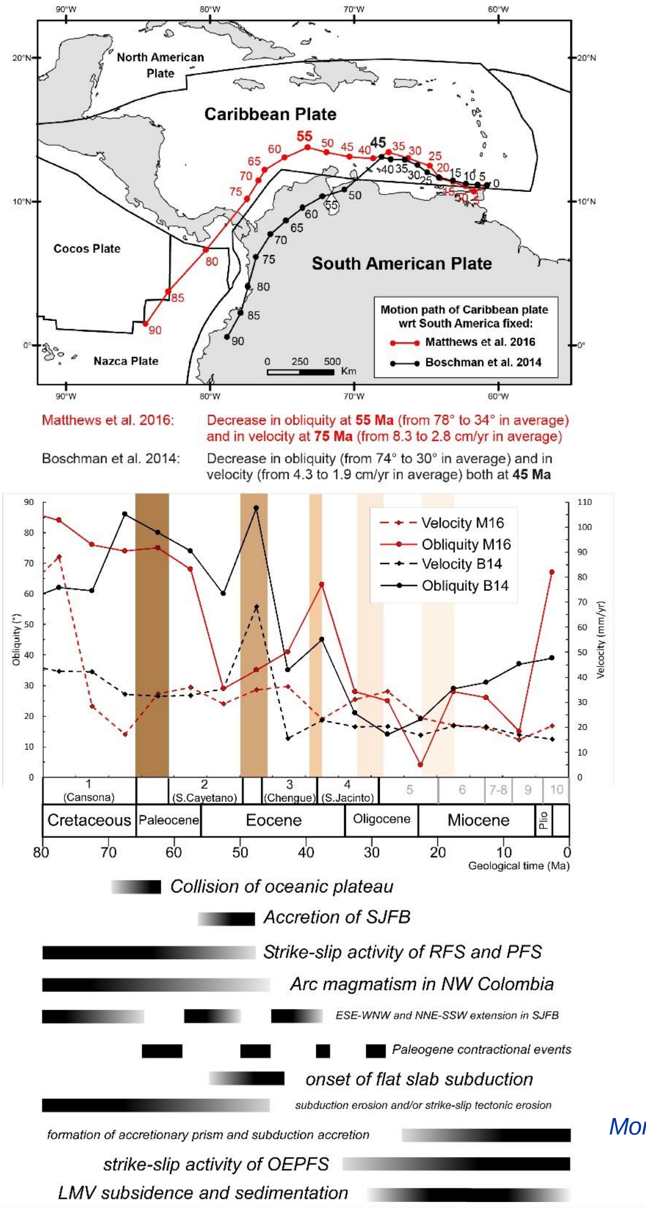


Mora et al., 2018



Gomez et al., 2007

Introduction: Formation of LMV & San Jacinto

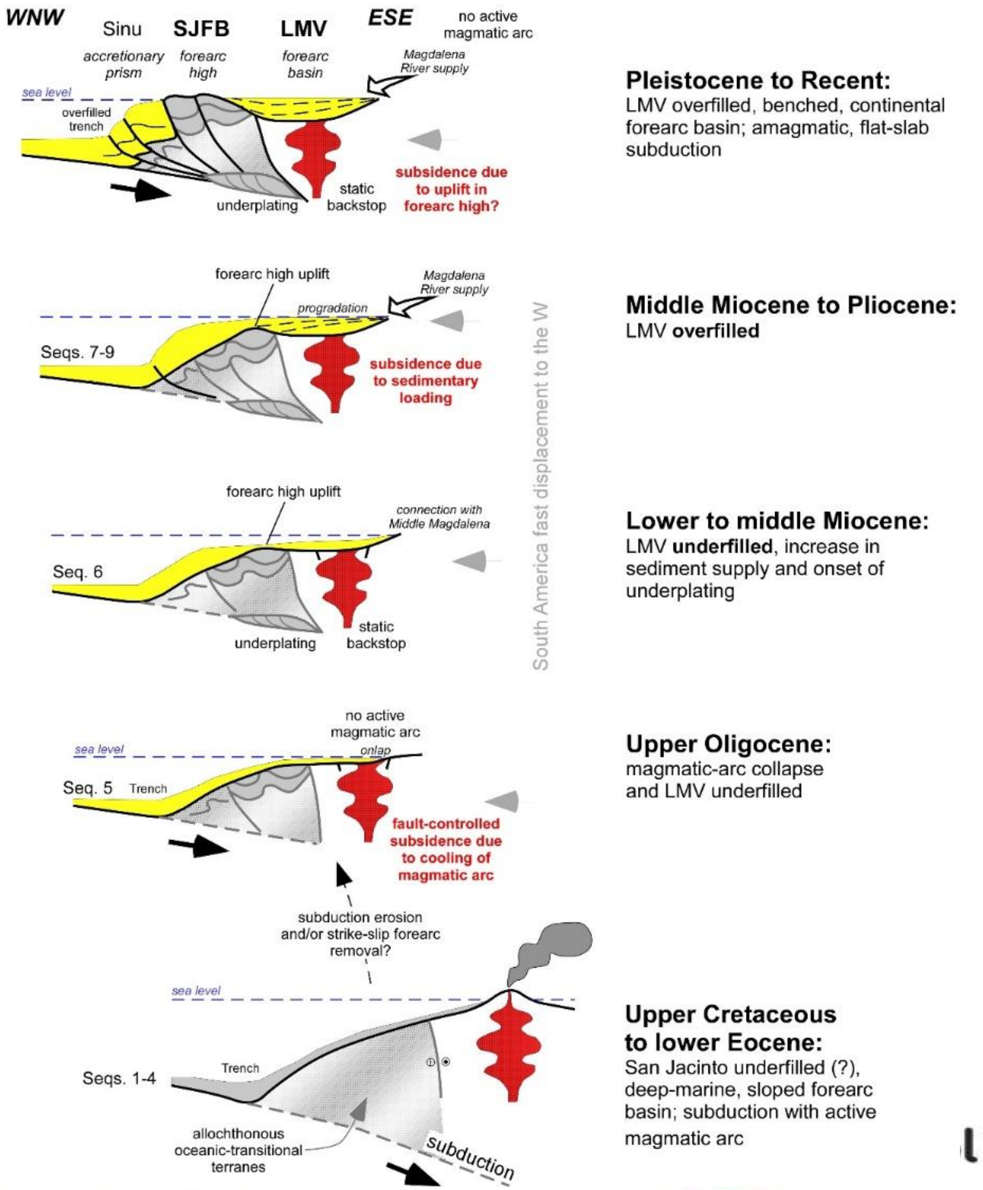


Mora et al., 2017b

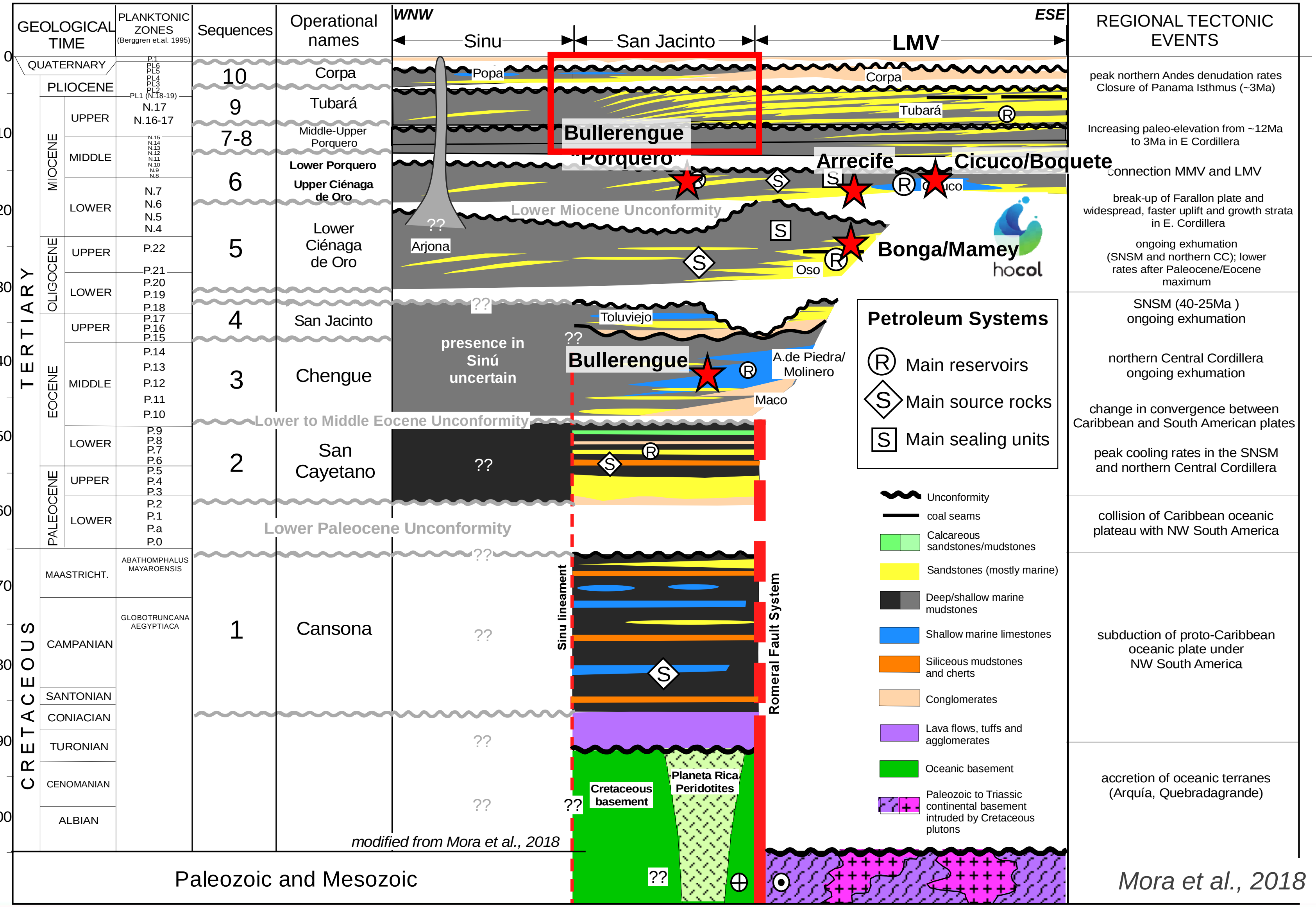
The San Jacinto fold belt is an intensely deformed, Cretaceous to Eocene forearc basin, related to the subduction of the Caribbean plate beneath South America, and its infill was strongly influenced by the interaction and re-adjustments of the different tectonic plates (Mora et al 2017b, left).

By contrast, the LMV is an overfilled, amagmatic forearc basin whose formation and infill were controlled by sediment influx (connection MMV-LMV), basement structure and flat subduction (Mora et al., 2018, right).

Mora et al., 2018

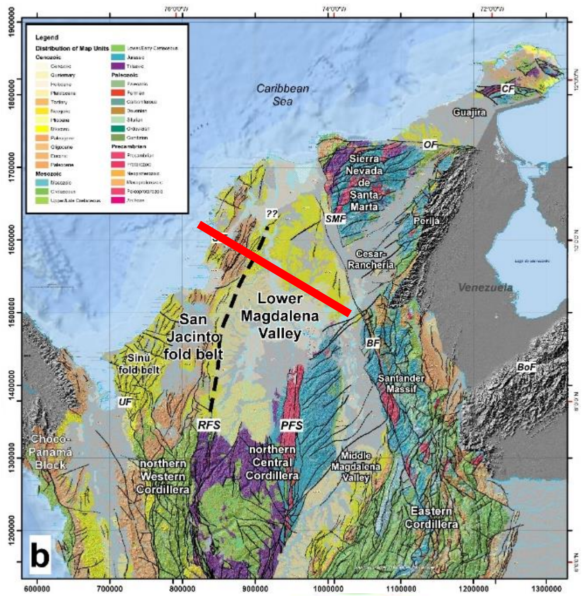


Introduction: Stratigraphy



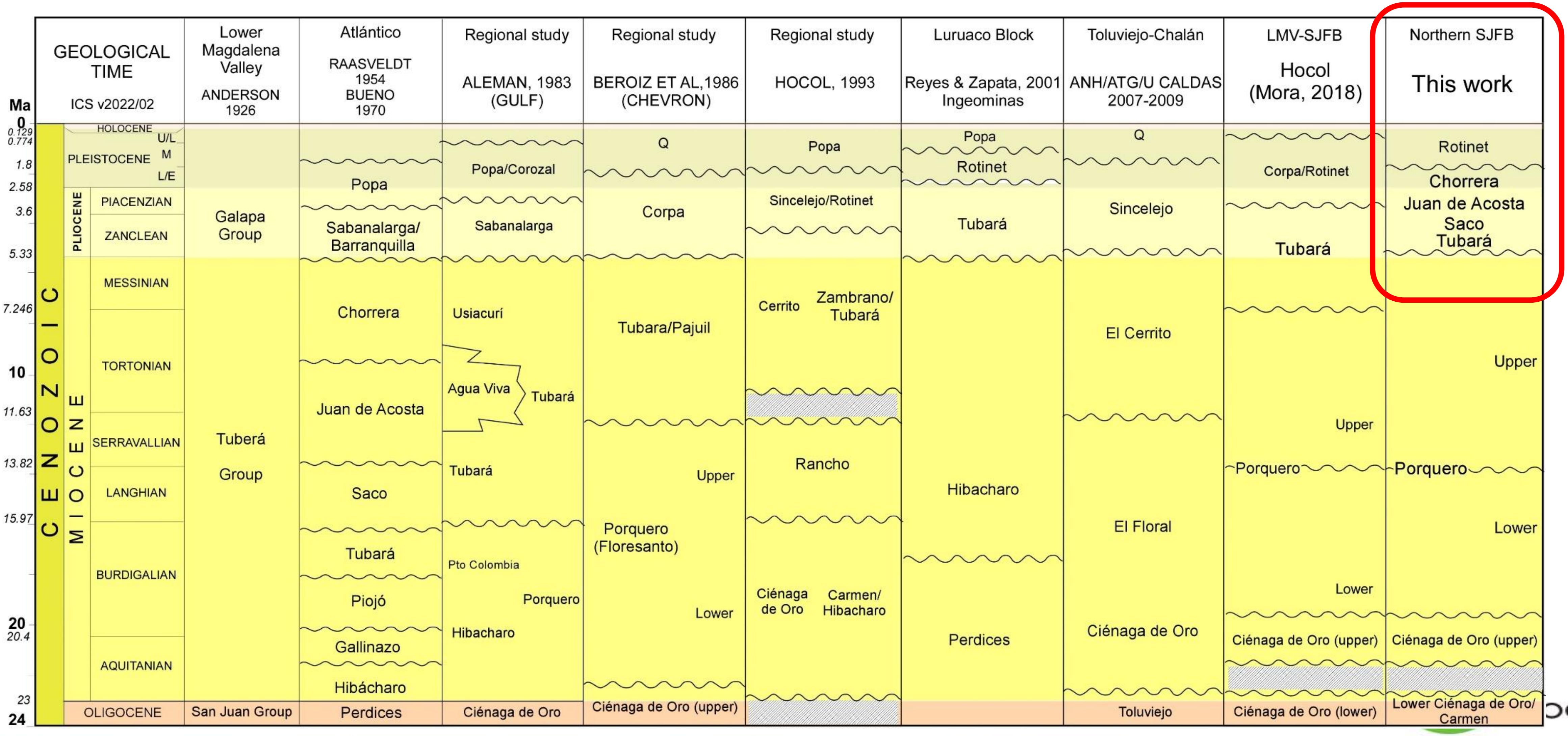
Mora et al., 2018

Deposition in an accretionary prism and forearc high, related to the flat subduction of the Caribbean plate beneath northern South America



Introduction: Stratigraphy

The stratigraphic succession of the Tubará-Juan de Acosta syncline would be younger than previously considered.



Methodology

Revision of bibliography and previous research

Field Geology			
Mapping, transects and stratigraphic columns (depositional environments & facies) with sample collection			ATG
Sample analyses:	biostratigraphy	palynology	Paleoflora
		micropaleontology (forams)	Stratos
	U-Pb DZ geochronology		U. of Arizona
	petrography & XRD/XRF		ATG

Stratigraphic wells			
Drilling, logging and coring			ANH
Detailed sedimentological core description, depositional environment & facies, sampling			Genesis
Sample analyses:	biostratigraphy	palynology	Paleoflora
		micropaleontology (forams)	Stratos
	petrography		Gmas

2D & 3D seismic interpretation	
Seismic tie to wells and outcrops	Hocol
Seismic interpretation & mapping in TWT of main sequences	
Depth conversion of maps using velocity model from 3D seismic and well data	
Structural maps in depth, thickness maps	

Data integration and analysis

Reconstruction of the evolution and infill of the Pliocene to early Pleistocene Tubará-Juan de Acosta syncline

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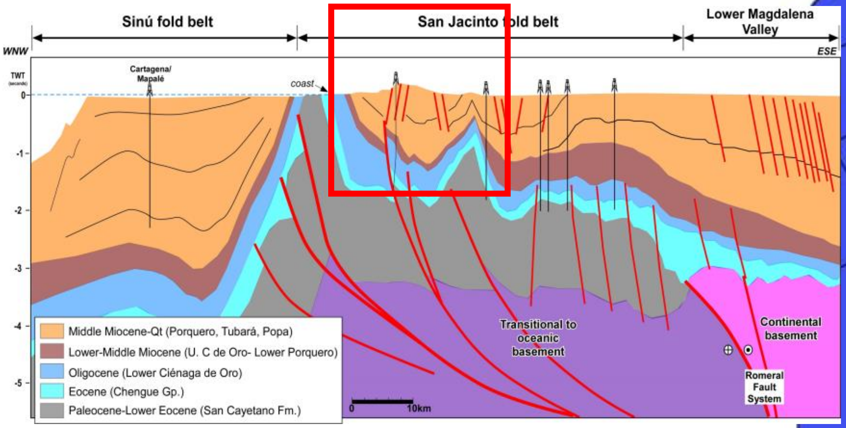
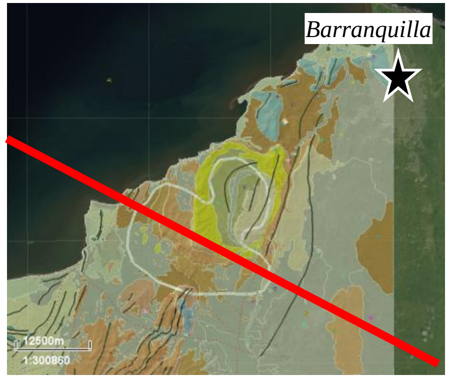
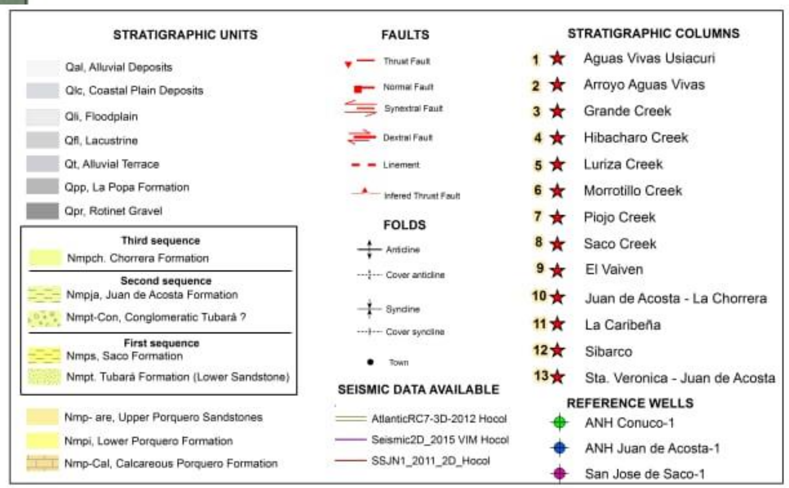
Geology & Database







- 2D and 3D-data (fair quality)
- Logs & cores from two stratigraphic Wells (ANH)
- Surface Geology including stratigraphic sections and sample collection for different lab analyses.

1. Cibarco Anticline
2. Tubará syncline
3. Sabanalarga syncline

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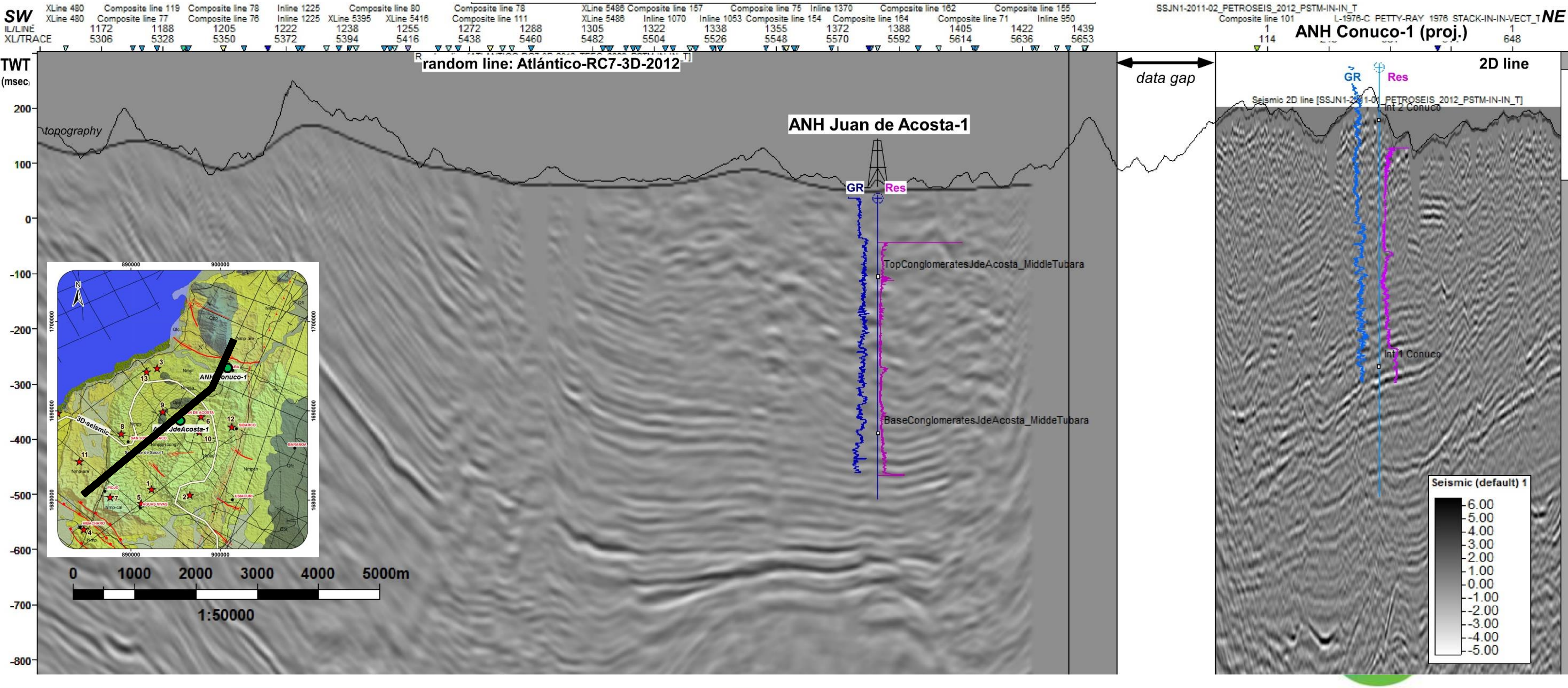
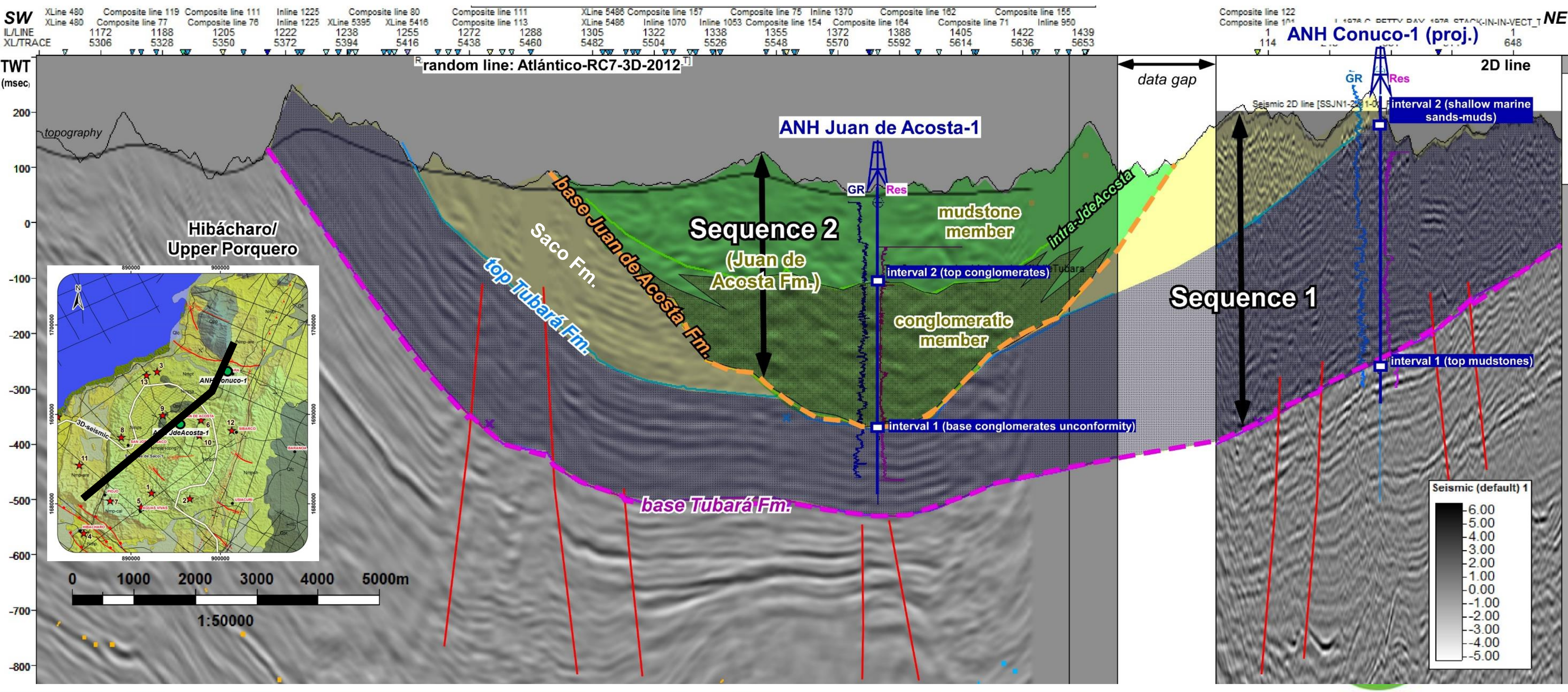
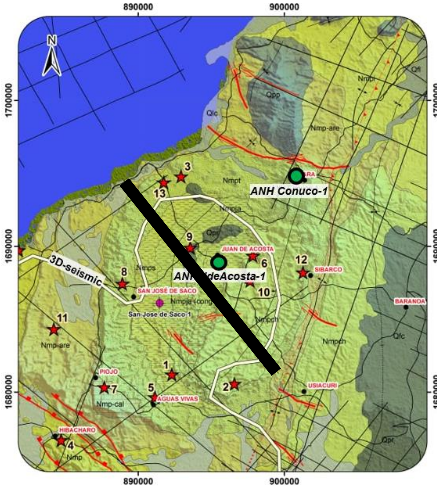
Seismic-well tie & interpretation

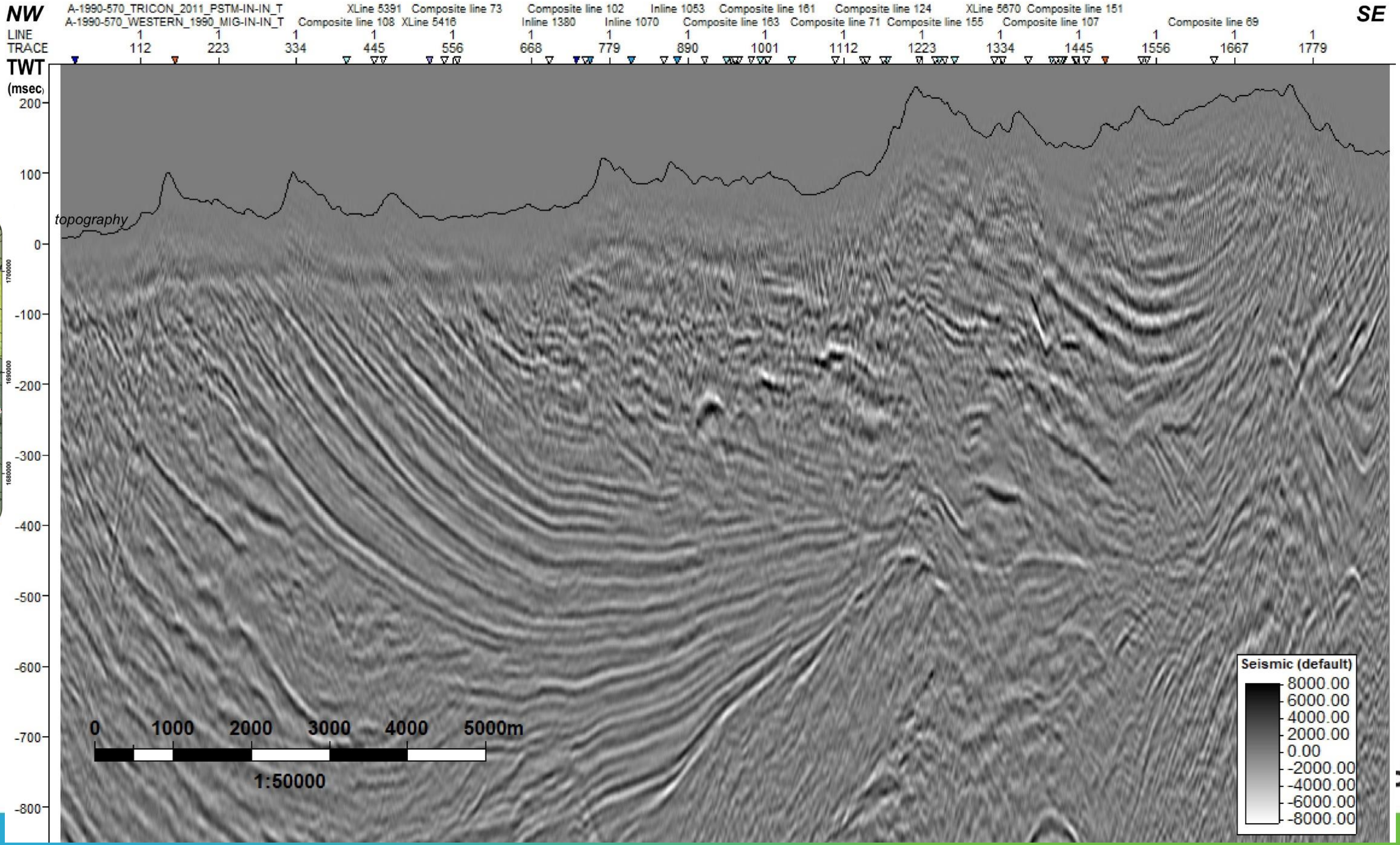


Seismic-well tie & interpretation



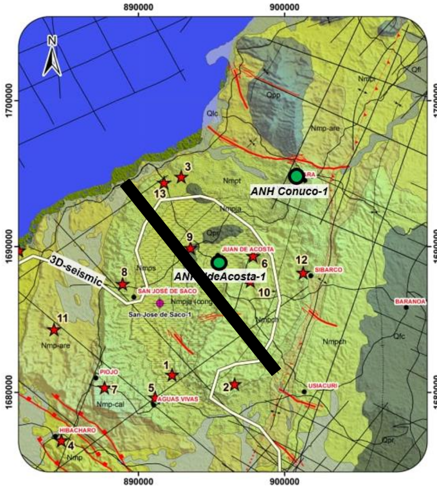
Seismic interpretation

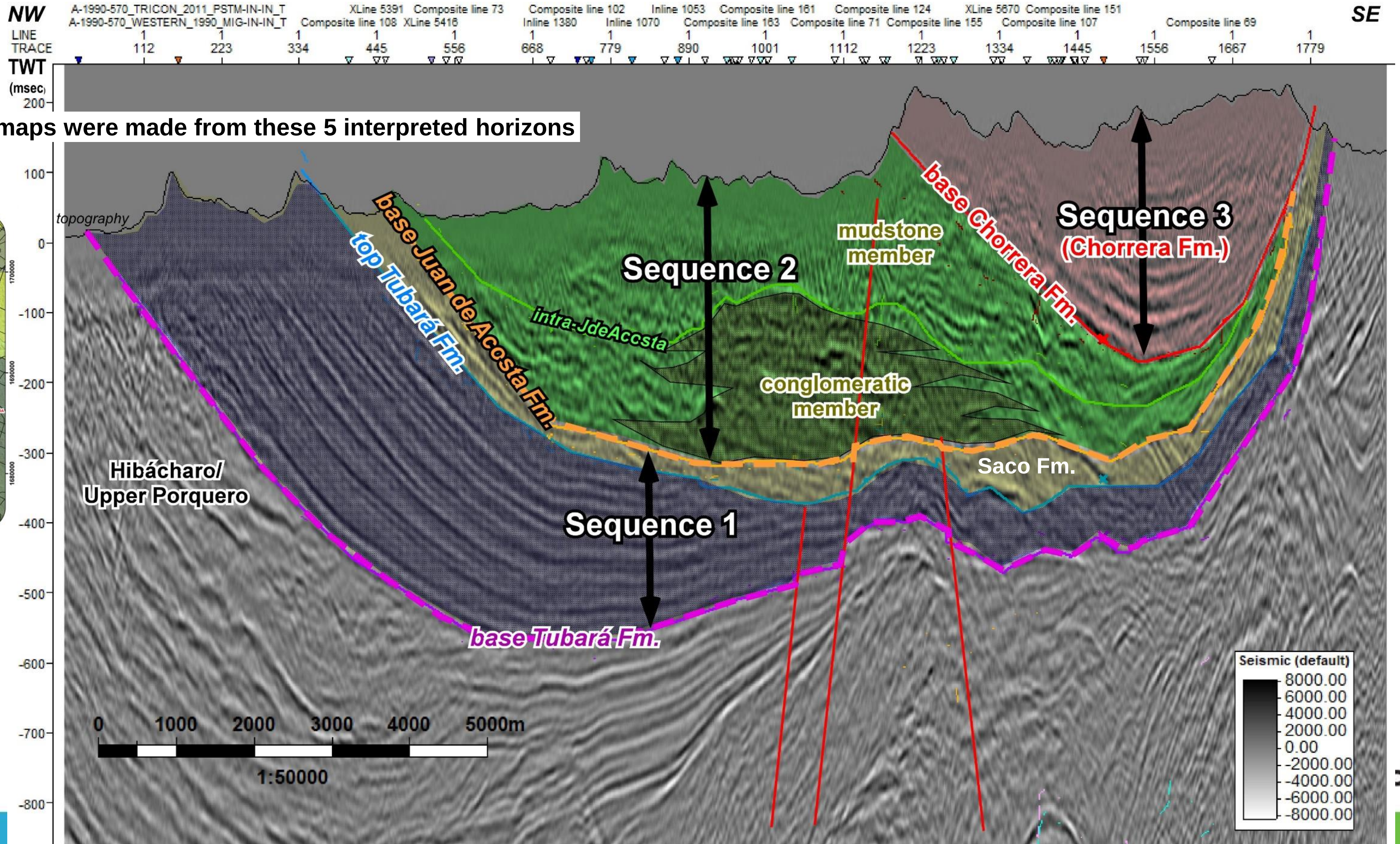




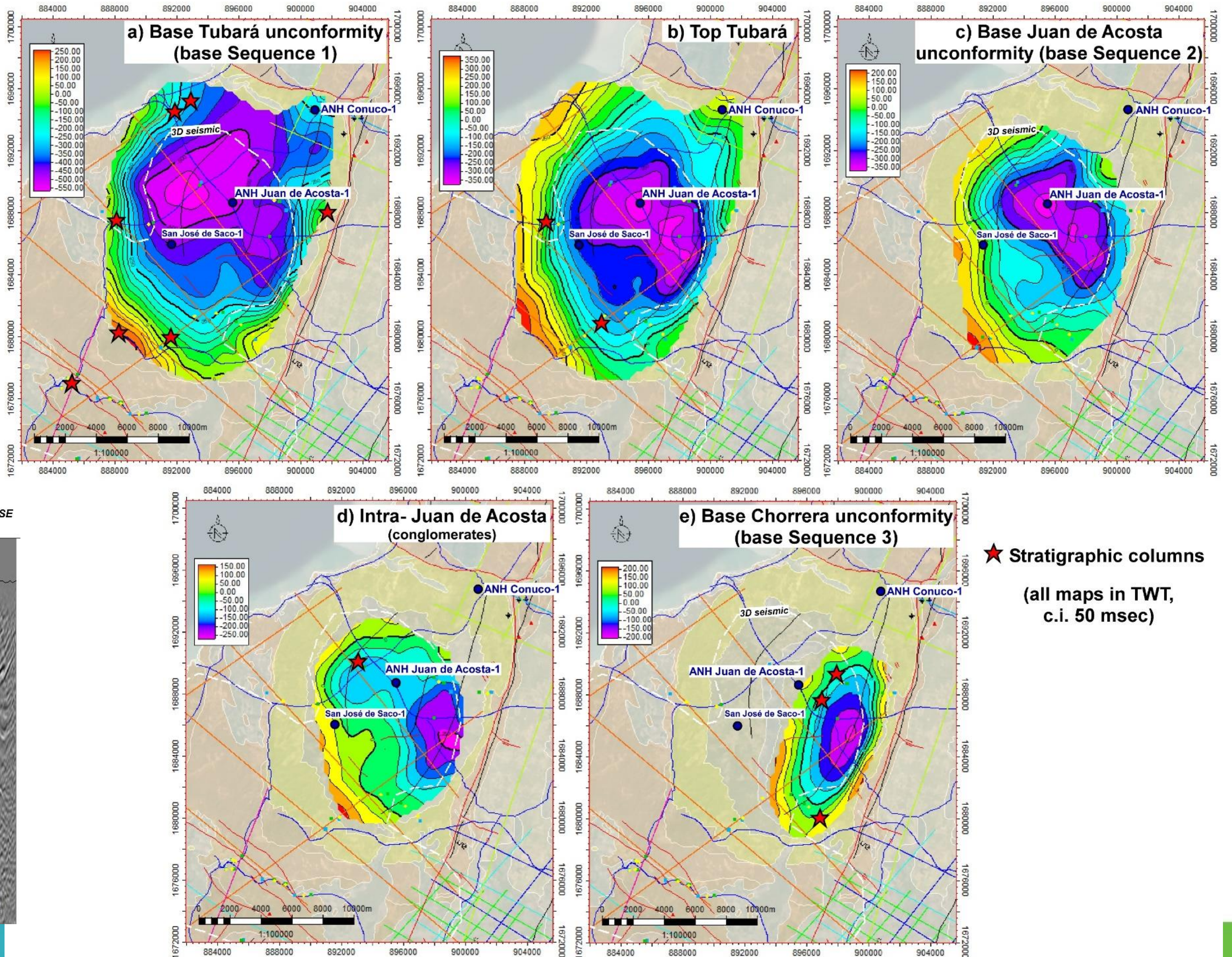
Seismic interpretation

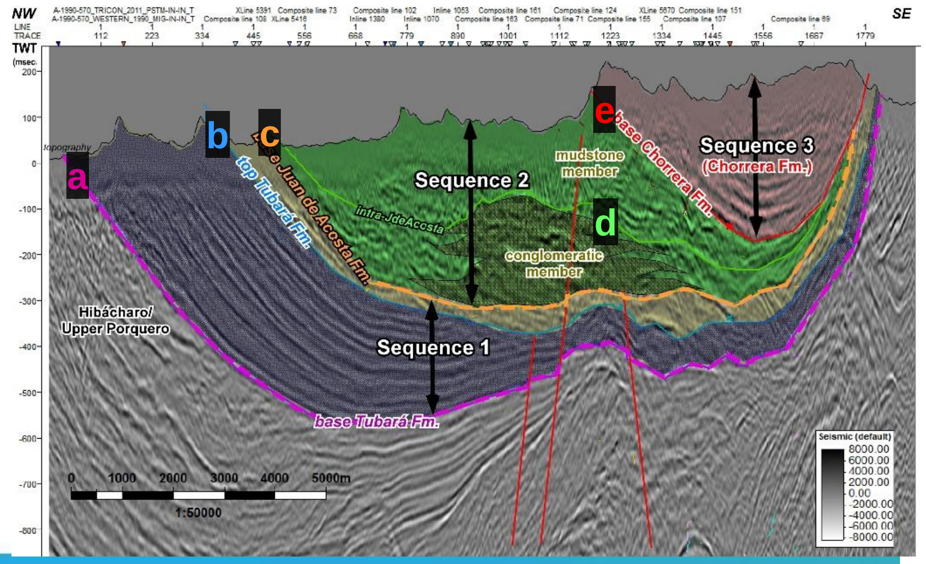
Structural and thickness maps were made from these 5 interpreted horizons





Structural maps (TWT)



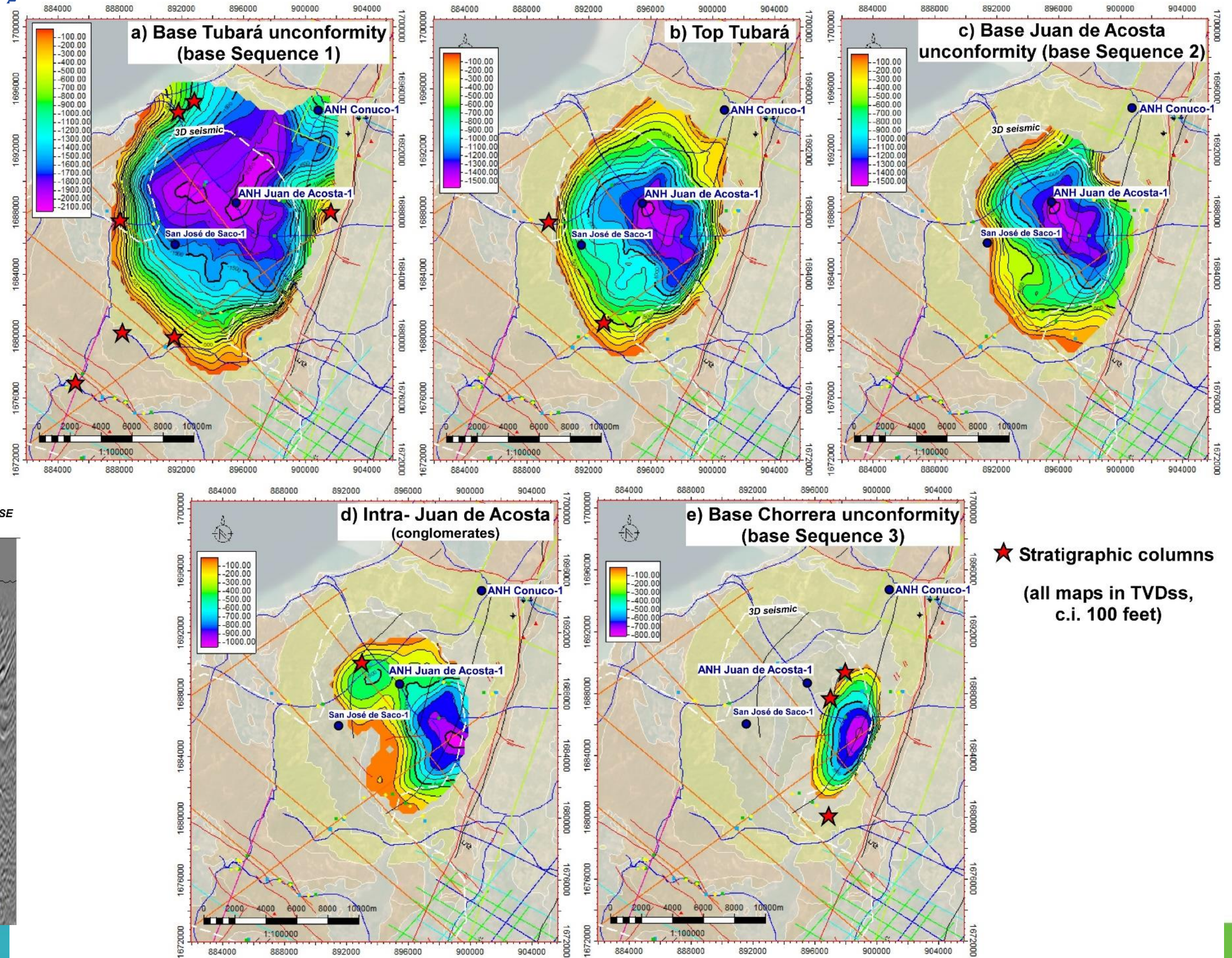


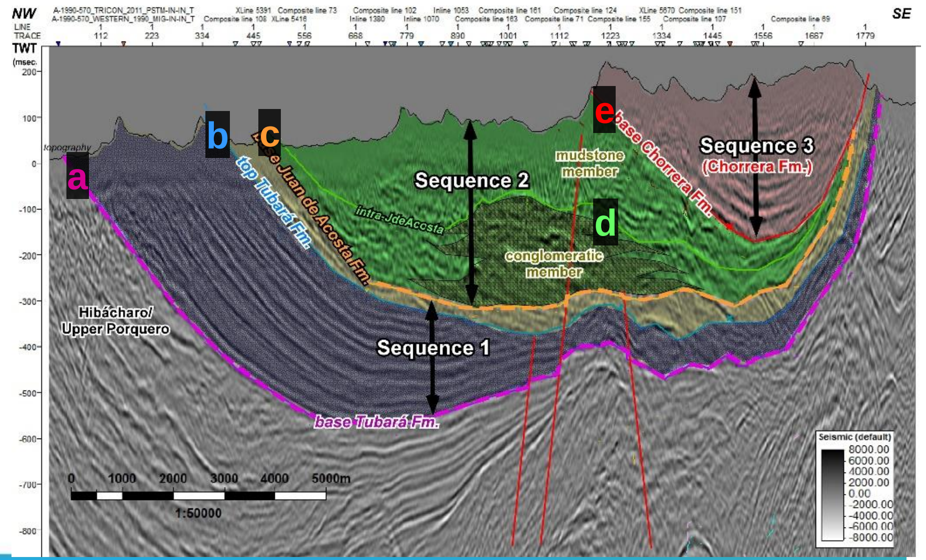
★ Stratigraphic columns

(all maps in TWT, c.i. 50 msec)

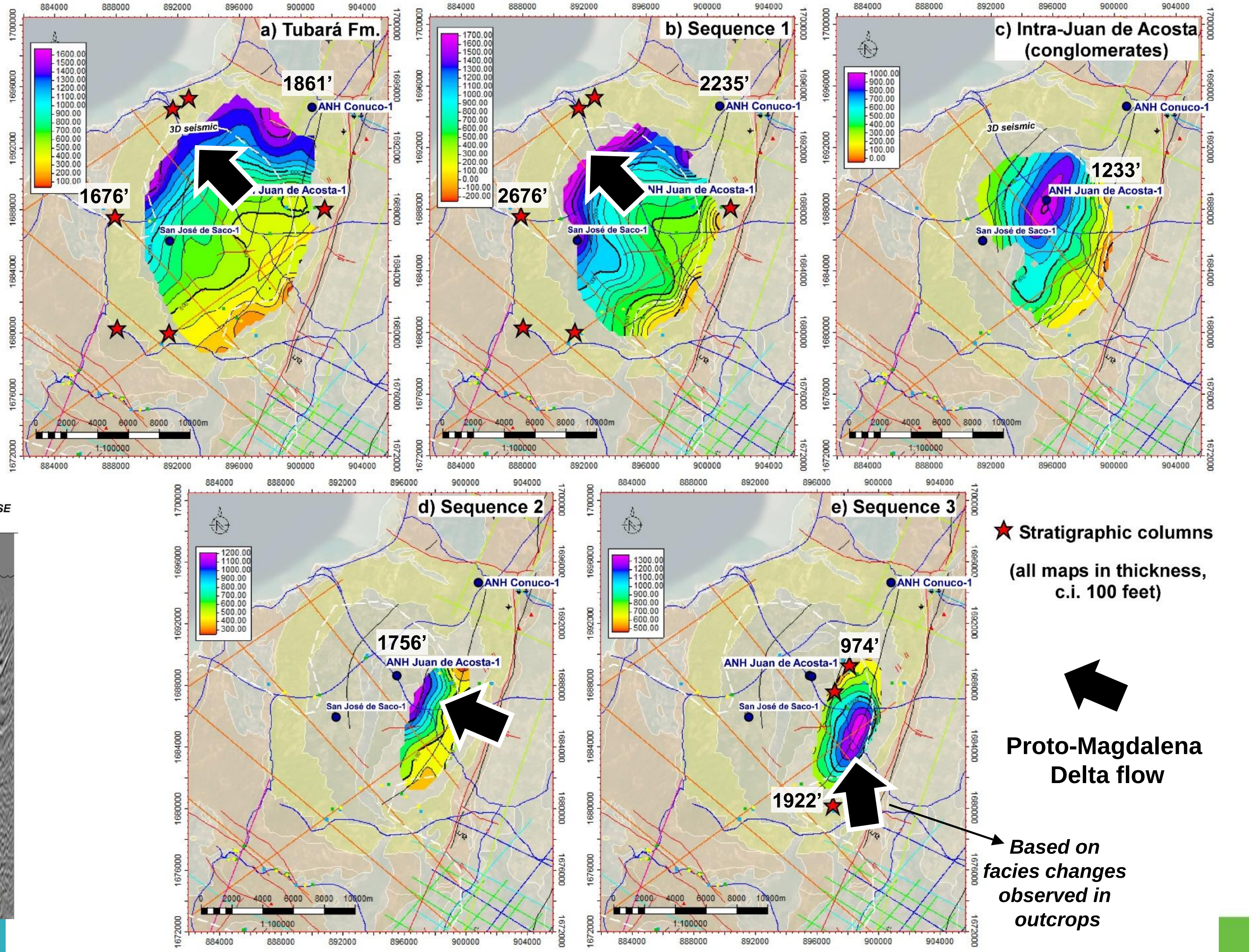
Structural maps (depth)

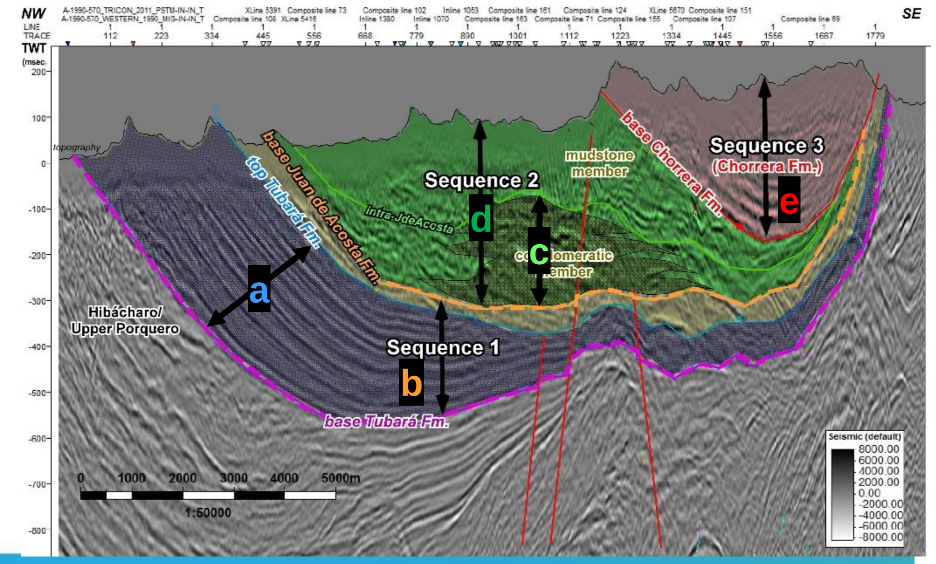
TWT structural maps were depth-converted using a velocity model obtained from the 3D seismic volume and using data from a few wells in the area





Thickness maps (feet)





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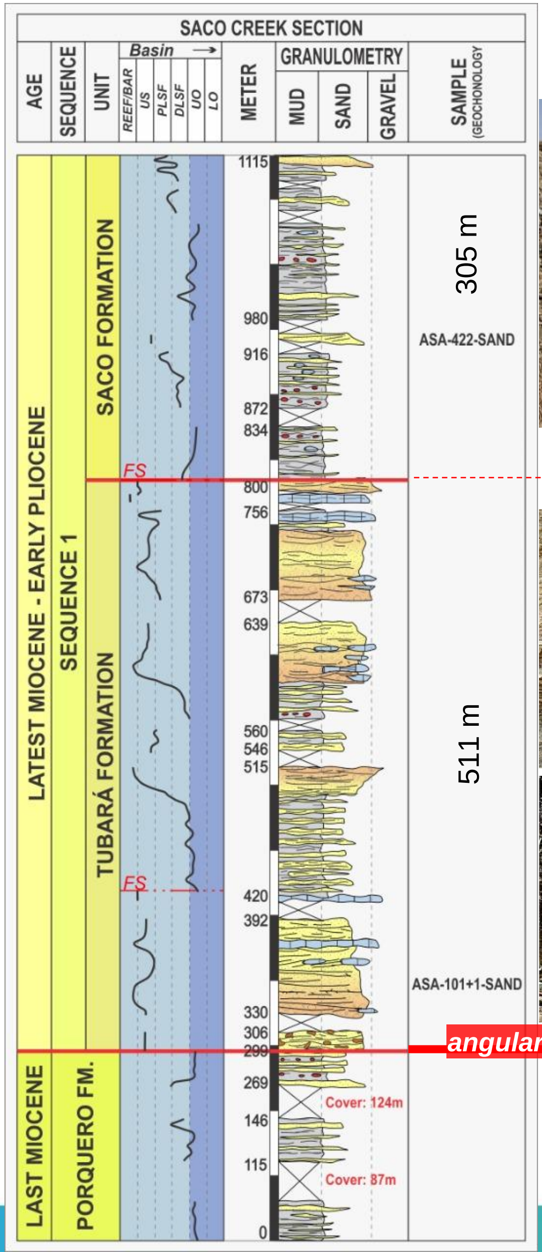
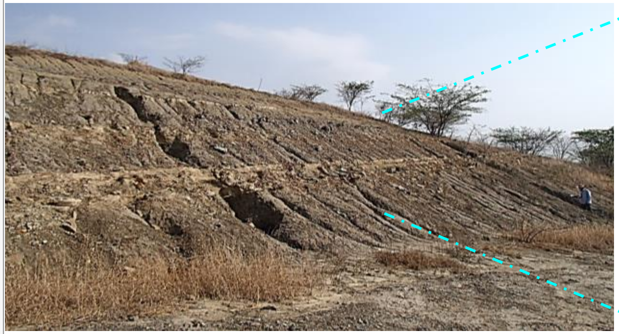
Tubará and Saco Formations (Sequence 1)

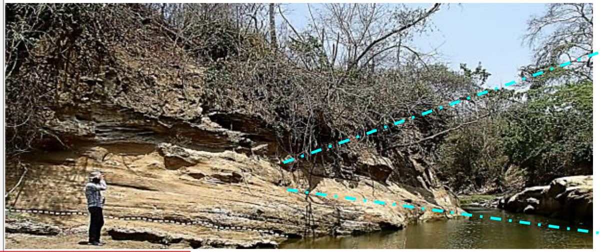


Arroyo Saco section- Sequence thickness: 816m (2676 ft)



Fossiliferous shales with fine-grained sandstone interbeds

Heterolithic succession of shales and sandstones with wave ripples



upper shoreface & foreshore, amalgamated fossiliferous sandstones mark the base of Tubará Fm.

angular unconformity

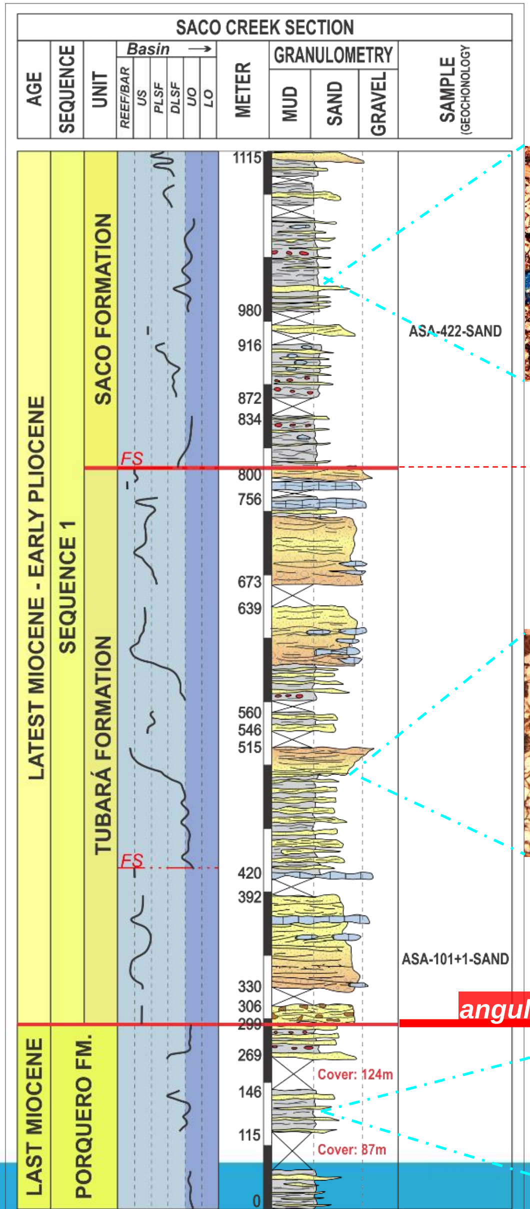
Bluyish-grey shales with fine-grained sandstone lenses (marine shelf deposits).

Biostratigraphy:
Latest Miocene to Pliocene

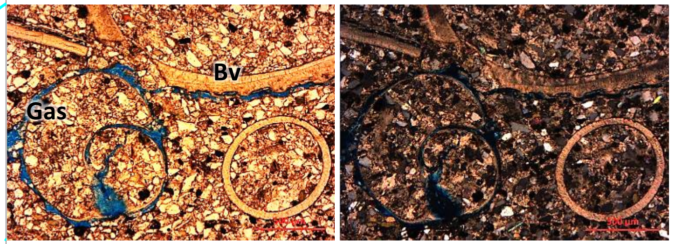
U-Pb DZ Geochronology:
Pliocene (6.7- **4.7 Ma**)

Tubará and Saco Formations (Sequence 1)

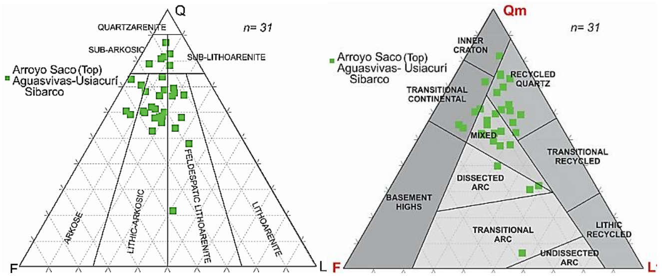
P.S.: these sandstones have good reservoir quality, but they are outcropping or found at very shallow depths. Hence their role is as overburden rocks. Potential reservoir in offshore areas.



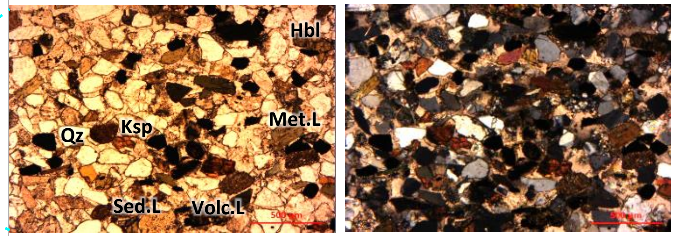
Arroyo Saco section



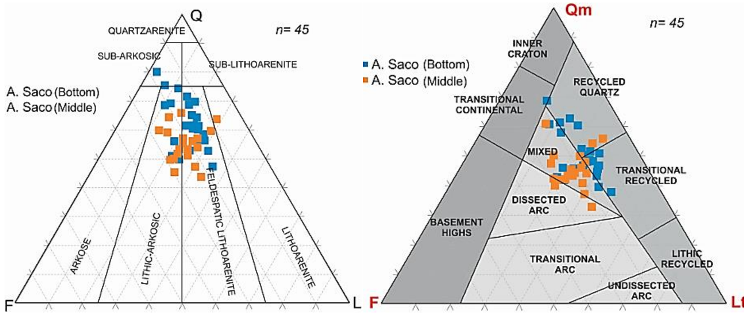
- Fossiliferous sandy marl



- Total porosity between **7-12%**, is mainly secondary due to moldic dissolution, and primary intergranular; considerable amount of bivalve and gastropods.
- Locally has sparry calcite (**3-15%**) and ferruginous cement (**2-13%**), with some minor traces of phosphate cement.

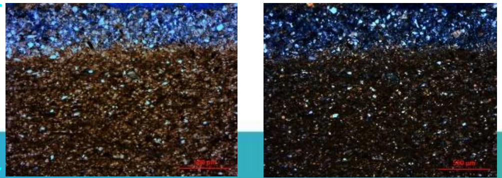


- Lithic arkose



- Total porosity between **3-15%,** locally can reach up to **25%**. Primary intergranular porosity (**4-12%**) and secondary porosity due to dissolution and fractures.
- High percentage of the samples have calcareous cementation, with can affect the total porosity, as well as ferruginous cement.

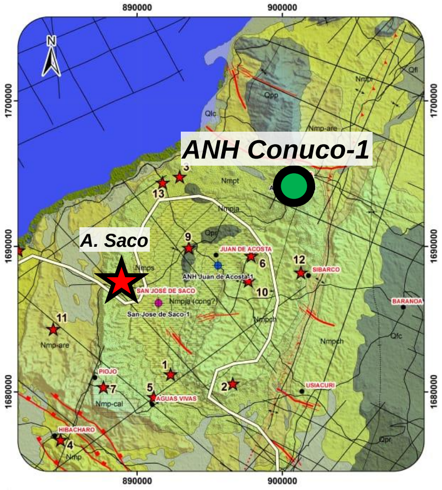
angular unconformity



- Fossiliferous sandy marl

- Total porosity between 5-**7%,** locally cemeted by sparry-calcite

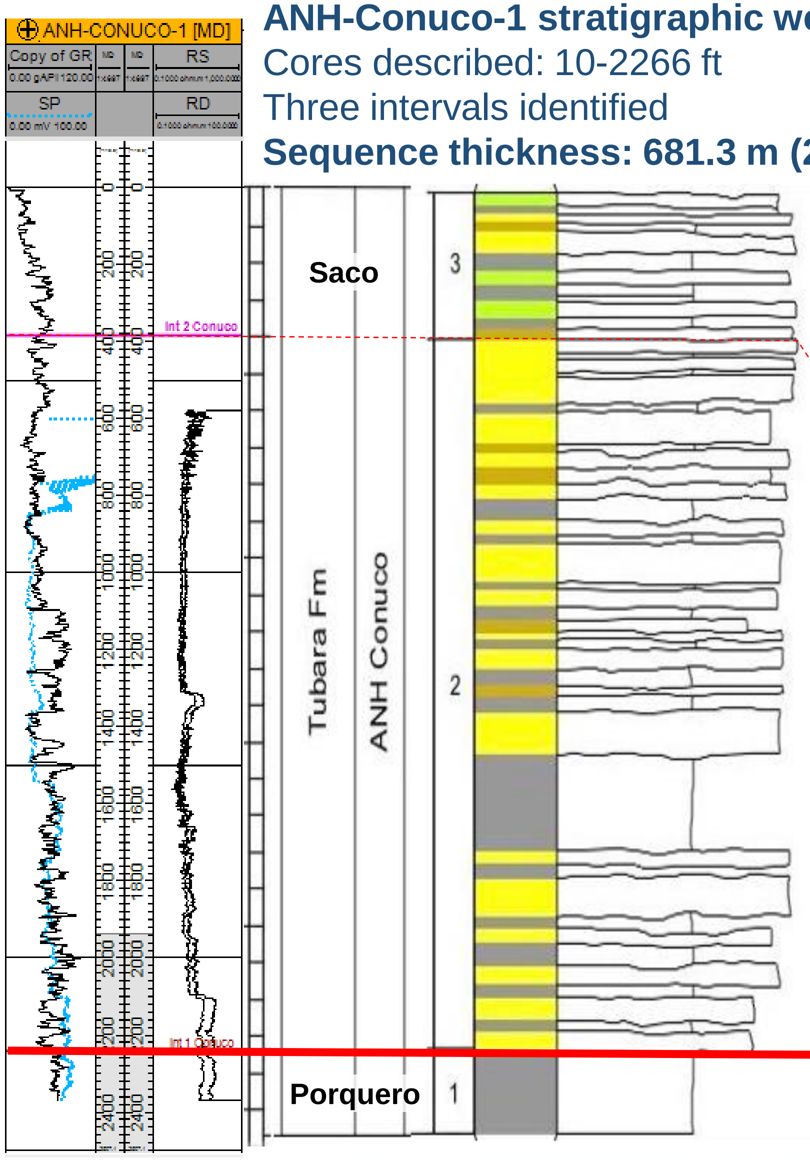
Tubará and Saco Formations (Sequence 1)



Biostratigraphy:
Latest Miocene to Pliocene

(no geochronology)

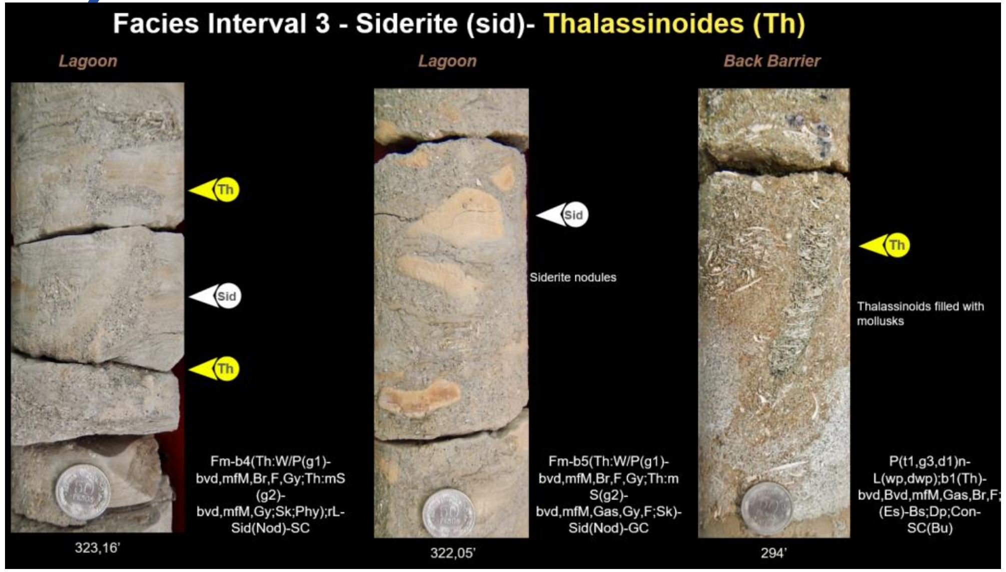
ANH-Conuco-1 stratigraphic well
Cores described: 10-2266 ft
Three intervals identified
Sequence thickness: 681.3 m (2235.4 ft)

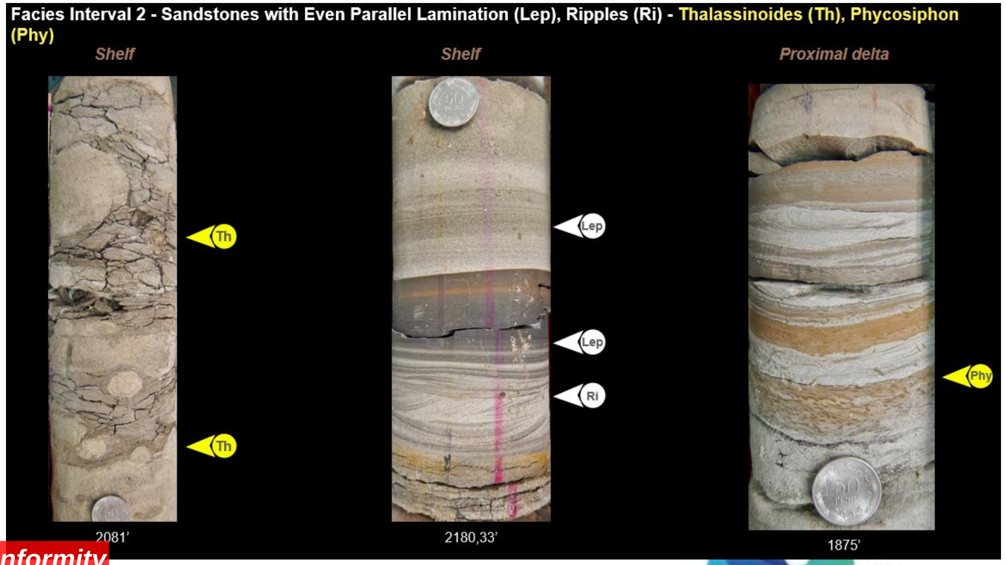


wave dominated deltas with beaches and strand plains

114 m (374 ft)

567.3 m (1861 ft)





unconformity

Interval 1: claystones with forams and disarticulated bivalve shells (shelf)

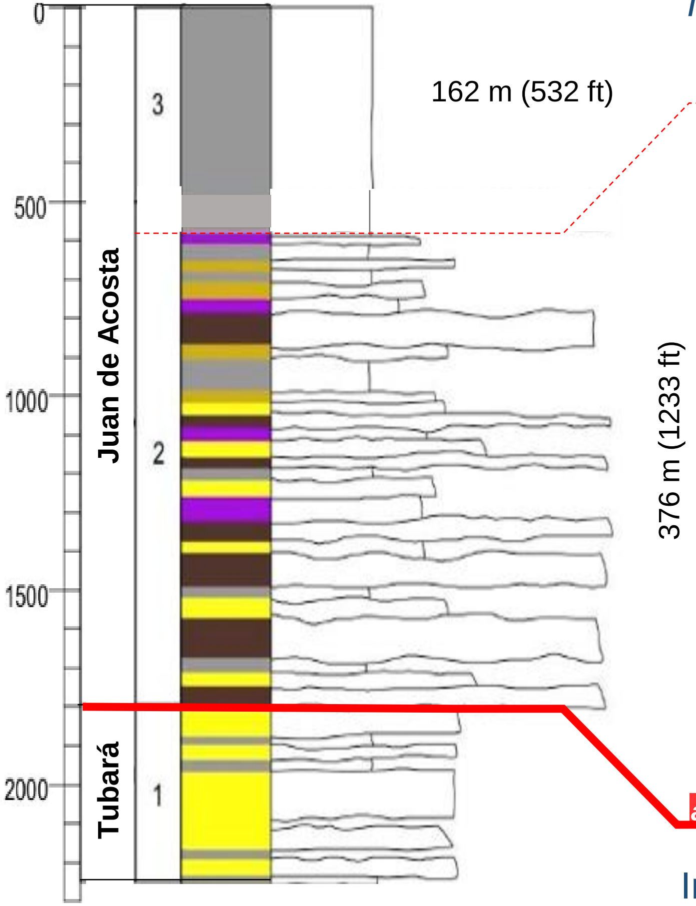
Juan de Acosta Formation (Sequence 2)

P.S.: though these sandstones have good reservoir quality, they are outcropping or found at very shallow depths. Hence their role is as overburden rocks.

Biostratigraphy:
Latest Miocene to Early Pliocene

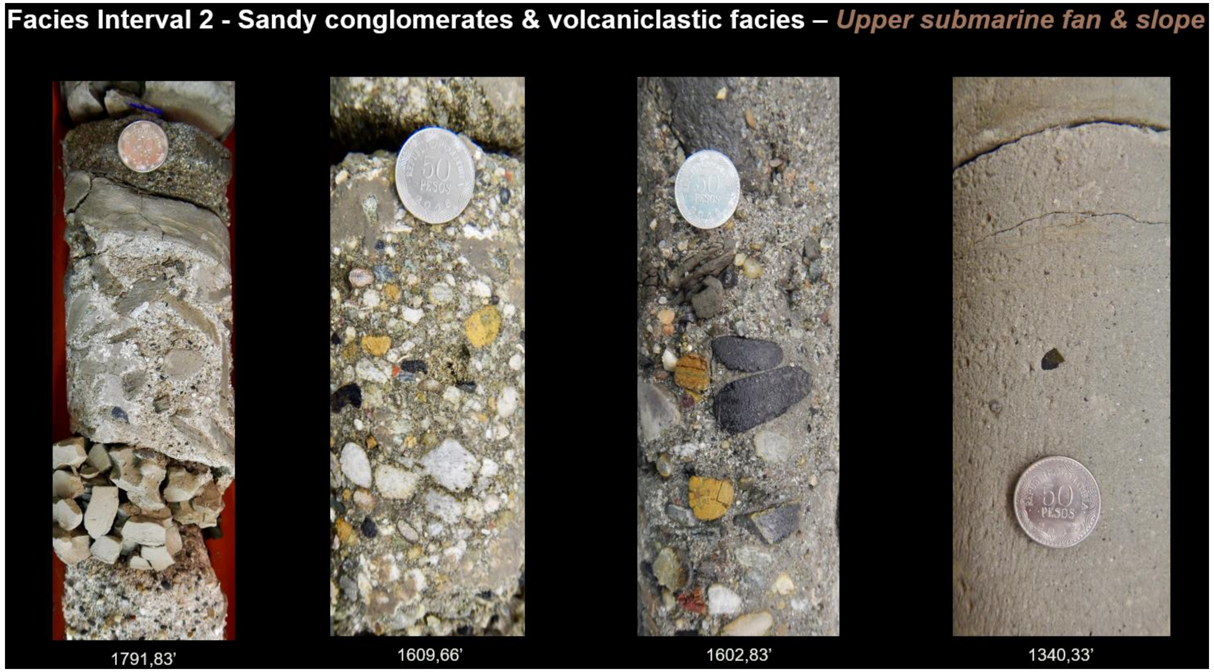
(no geochronology)

ANH-J. de Acosta -1 stratigraphic well
Cores described: 10-2266ft
Three intervals identified
Sequence thickness: 538.2 m (1766 ft)



Brown: conglomerates
Purple: volcaniclastic sands

Interval 3: mudstones with wavy parallel lamination, siderite laminae and *Thalassinoides* (outer shelf)

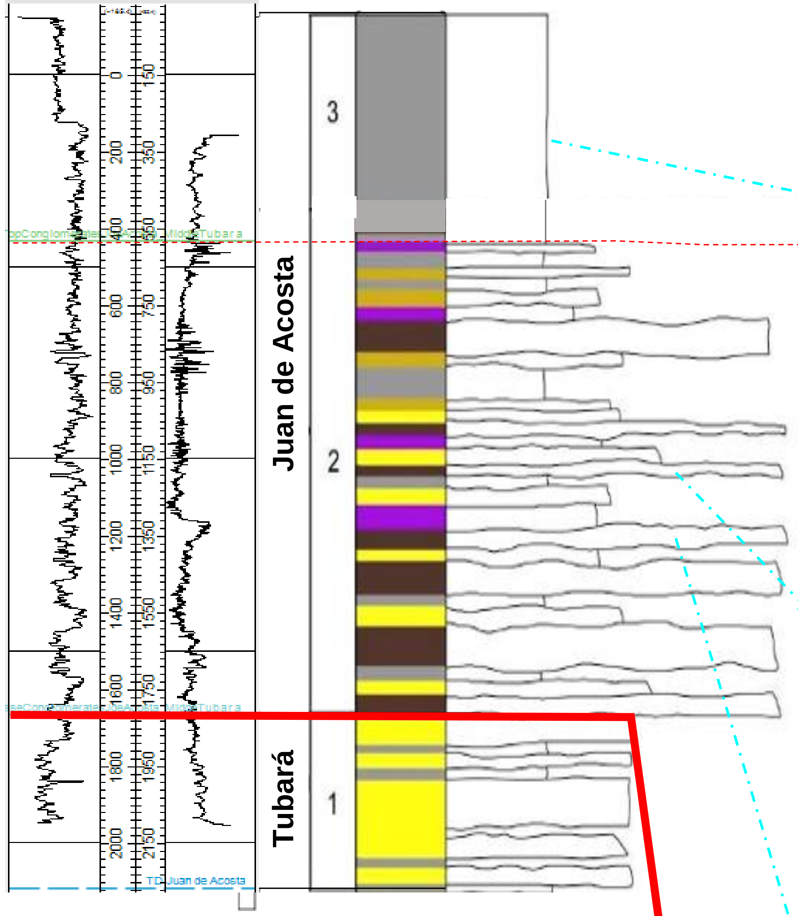


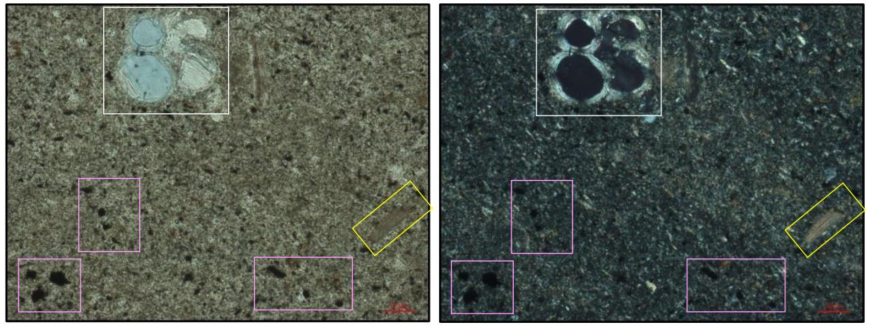
angular unconformity

Interval 1: sandstones with wavy ripples, hummocky cross stratification, even parallel lamination and with *Diplocraterion* & *Macaronichnus* (delta front, proximal prodelta and foreshore)

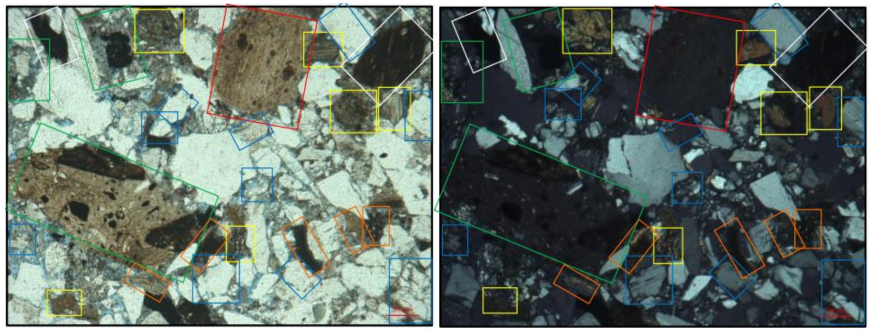
Juan de Acosta Formation (Sequence 2)

ANH-Juan de Acosta -1

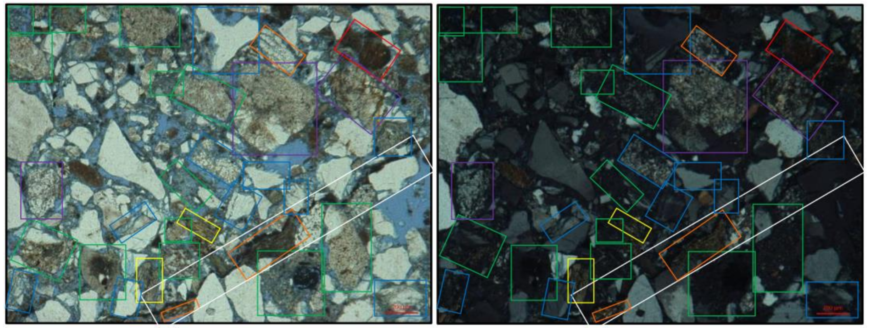




329’: Silty, volcaniclastic claystone with forams & organic detritus (pink rectangles).



1190.46’: Fairly-sorted & middle-grained, volcaniclastic, lithic-feldspathic arenite.



1353,17’: Fairly-sorted & middle-grained, volcaniclastic, lithic-feldspathic arenite

Juan de Acosta mudstone mbr. (Interval 3):

- Silty, volcaniclastic claystones with quartz, feldspar (plagioclase), possible glass shards, calcareous bioclasts and organic detritus.

Juan de Acosta conglomeratic mbr. (Interval 2):

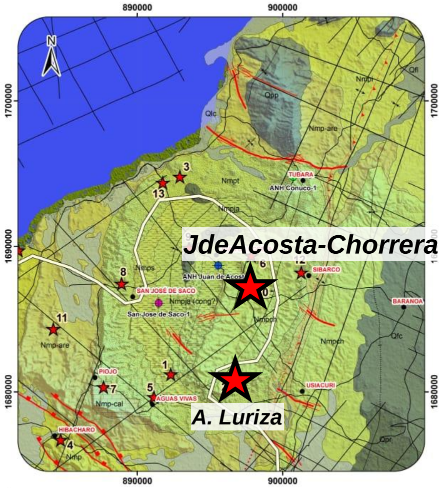
- Total porosity between **2-19% (average 7.6 %),** it is mainly secondary due to dissolution of unstable grains such as volcanic lithics and feldspars, also some fracture porosity.
- Main lithics are volcanic, low-grade metamorphic, sedimentary; other terrigenous grains are polycristalline quartz, micas and heavy minerals.
- Mudstone matrix, with organic matter detritus, zeolites, authigenic claystones, traces of siderite and glauconite.

angular unconformity

hocol

Green rectangles: volcanic rocks; blue rectangles: feldspars; yellow rectangles: hornblende;Orange rectangles: micas & metamorphic rocks; red and white rectangles: chert & sedimentary rocks

Chorrera Formation (Sequence 3)



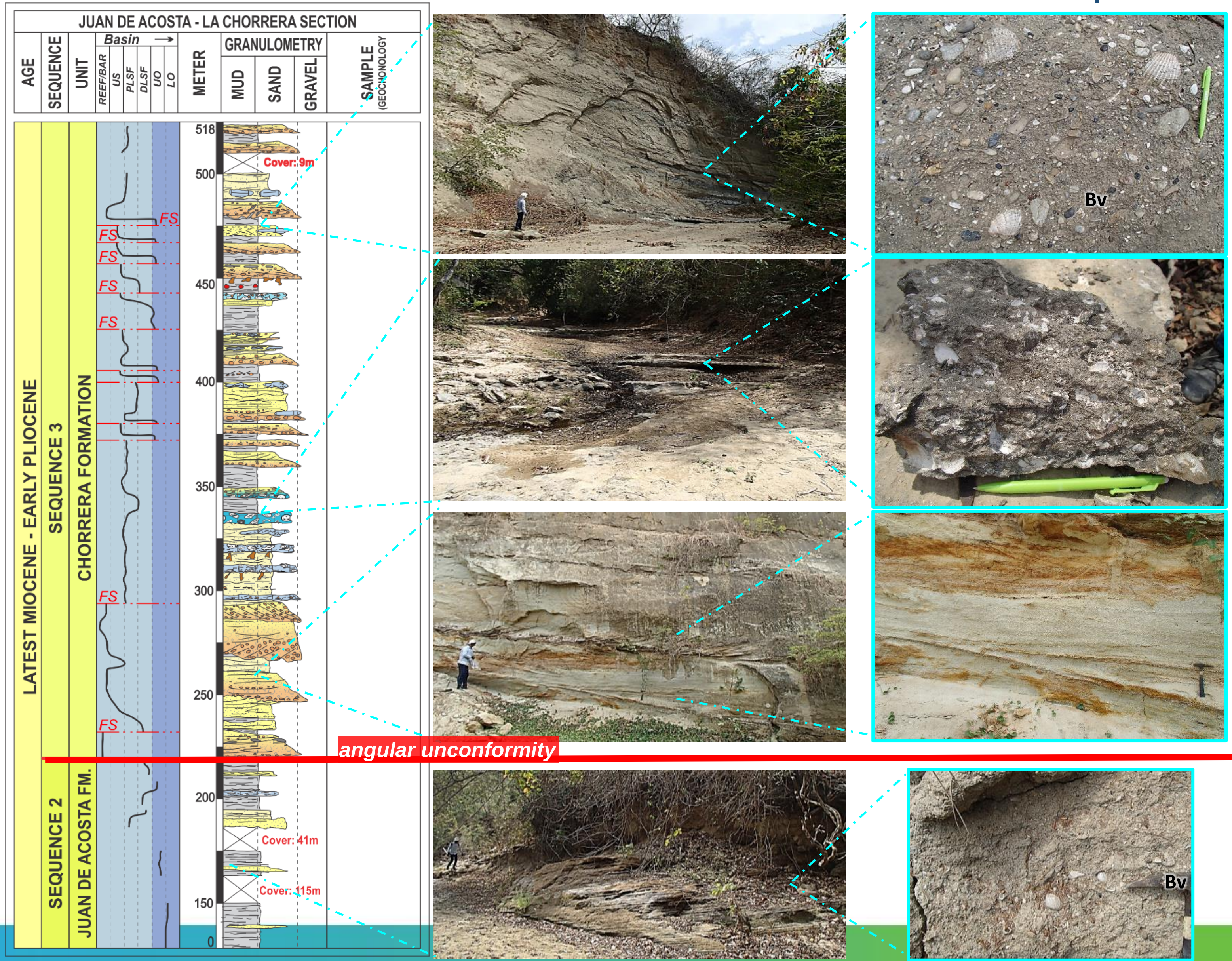
Biostratigraphy:
Pliocene to Pleistocene

U-Pb DZ Geochronology:
Late Pliocene to Early Pleistocene (3.5- 2 Ma)

Depositional environment: estaurine channels, bars and bays, with more marine influence to the N.

*thickness in A. Luriza is 585m (1922 ft)

Juan de Acosta-La Chorrera section- Sequence thickness: 297m (974 ft)*



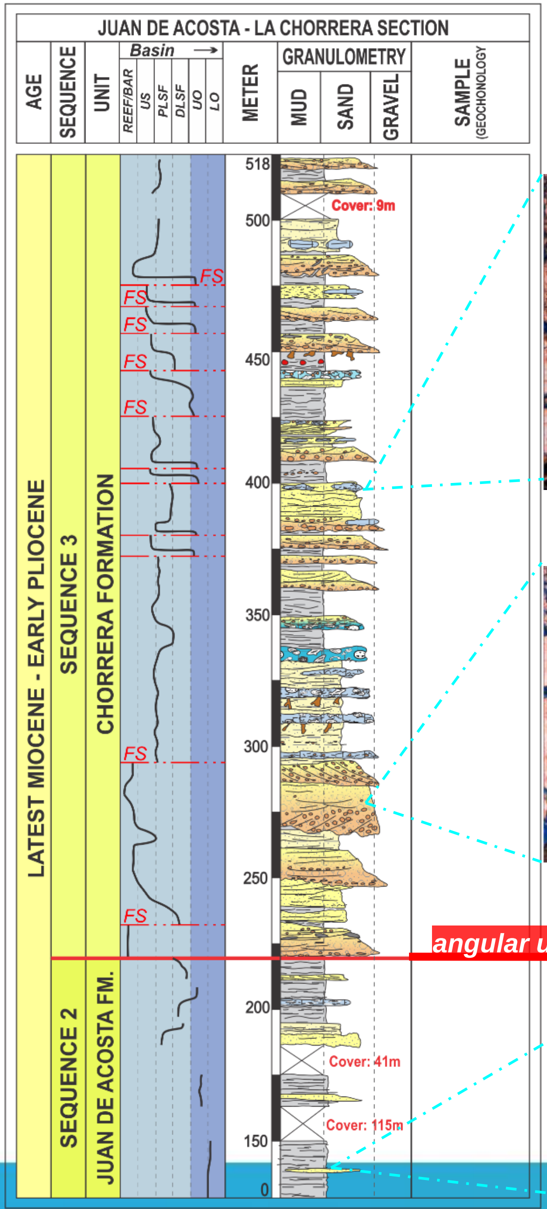
Interpositions of bioclastic conglomeratic sandstones and shales, with calcareous sandstone lenses

Impure rudstone biosparites of gastropods and bivalves

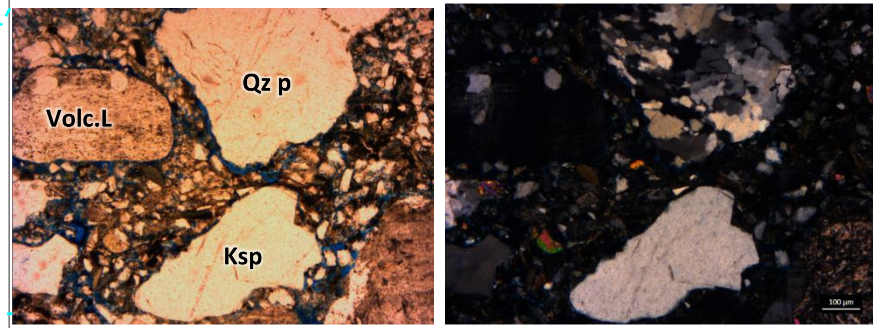
Amalgamated sandstones with trough, cross-bedding and herringbone stratification (barrier Island)

Dark-grey shales with foraminifera, bivalves and gastropods

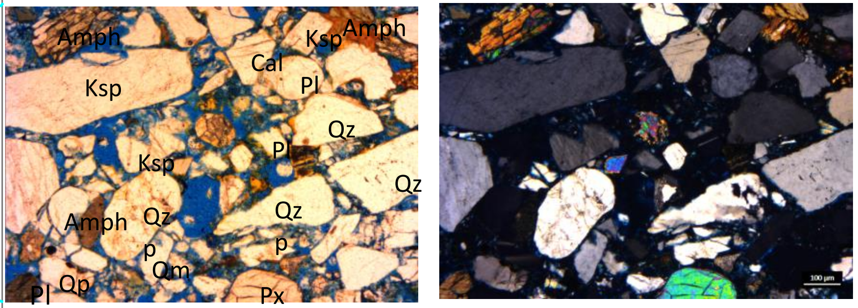
Chorrera Formation (Sequence 3)



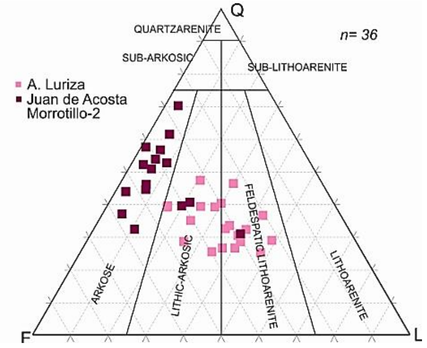
Juan de Acosta-La Chorrera section

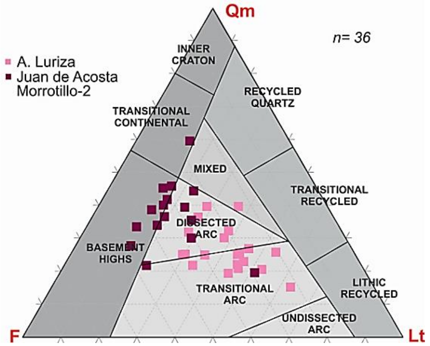


• Coarse-grained arkose



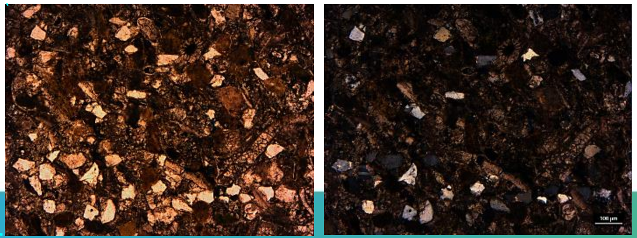
• Coarse-grained Lithic arkose





- Total porosity between **10-20%,** mainly secondary by fractures and primary intergranular.
- Increase of alkaline feldspar (**10-20%**) and polycrystalline quartz (**5-8%**) towards the top.
- Locally cemented by sparry-calcite

angular unconformity



• Bio-pelsparite

- Total porosity between 5-7%, locally cemeted by sparry-calcite, high glauconite content

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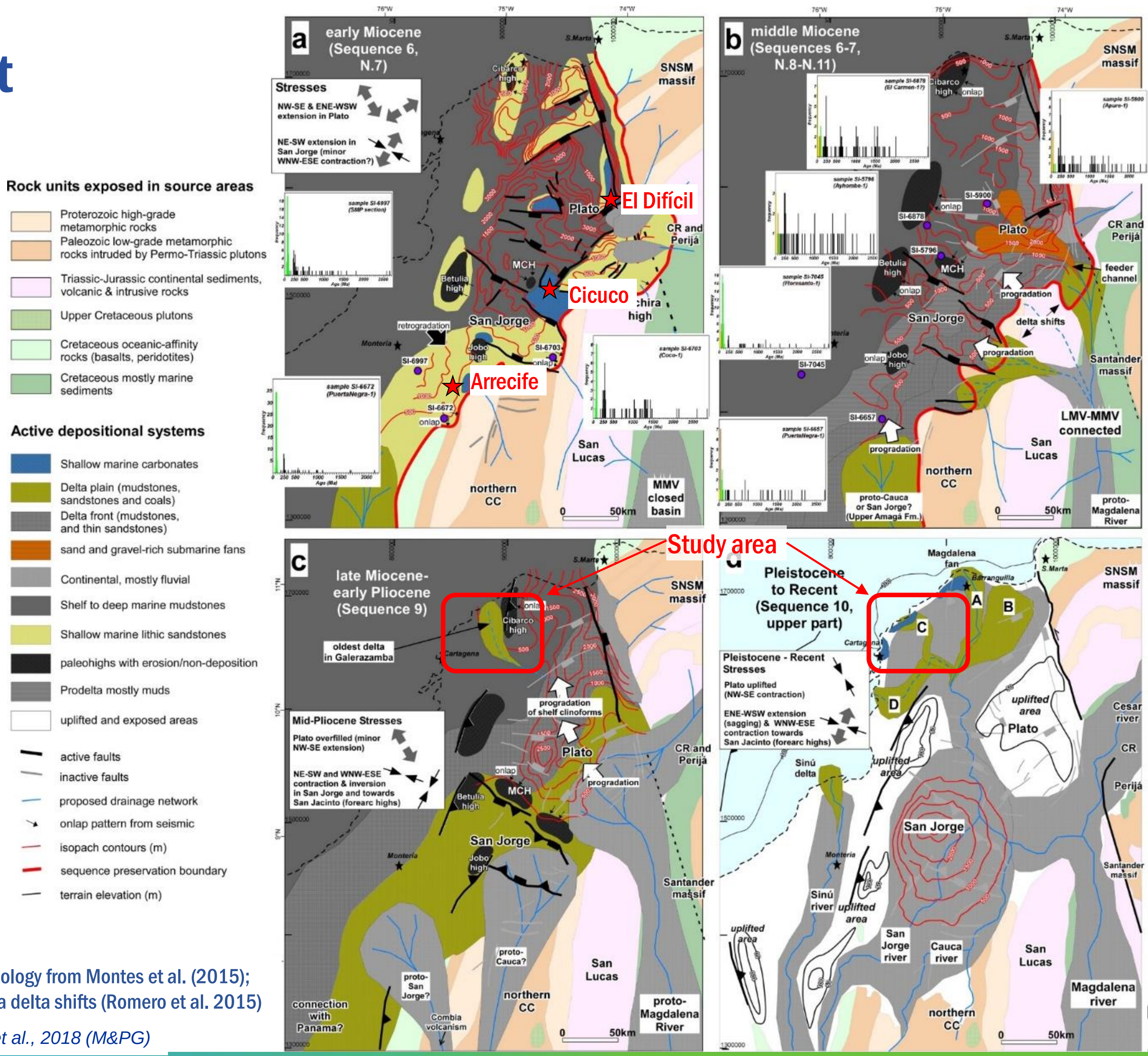
Early Miocene to Recent Paleogeography

Deposition in LMV of early Miocene sources and reservoirs occurred in a forearc, flat-subduction setting, controlled by the proto-Magdalena fluvial system.

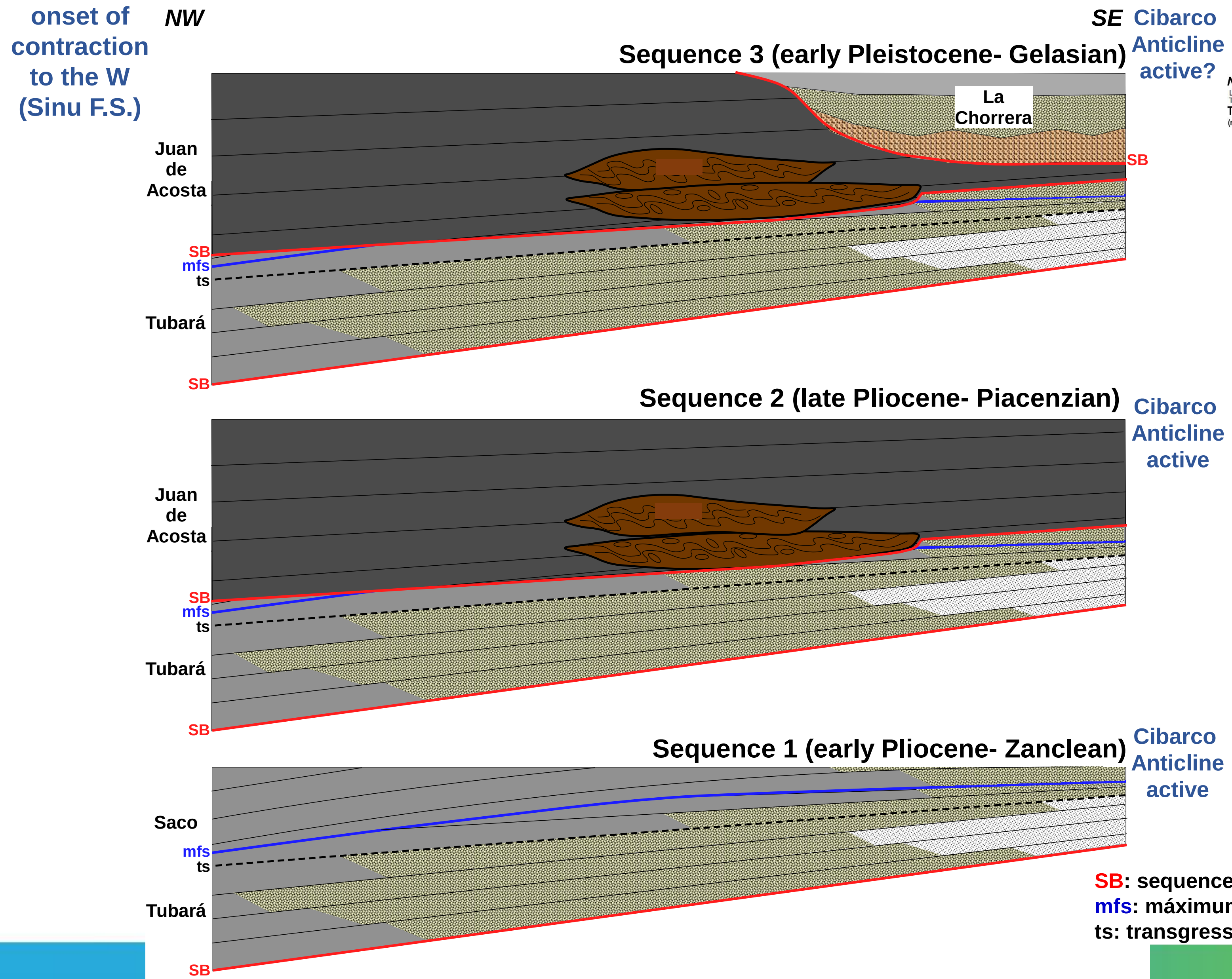


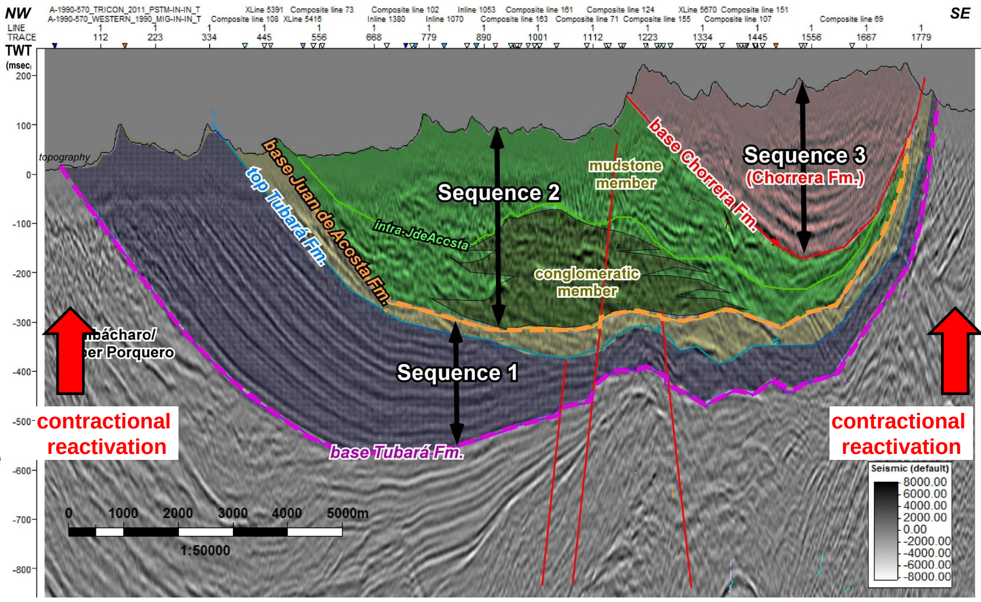
★ fields

U-Pb detrital zircon geochronology from Montes et al. (2015);
A-D in d represent Magdalena delta shifts (Romero et al. 2015)

Mora et al., 2018 (M&PG)

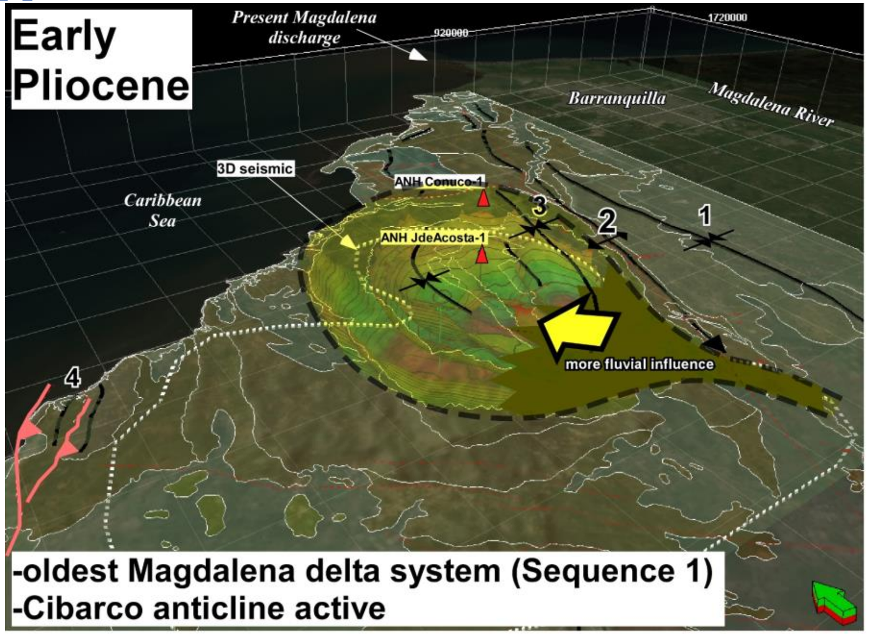
Stratigraphic model & basin fill

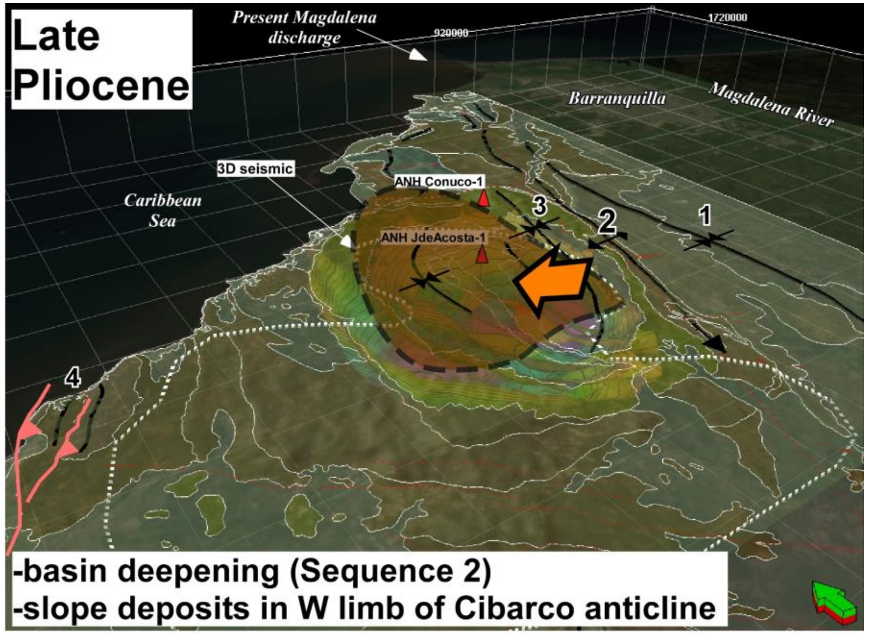




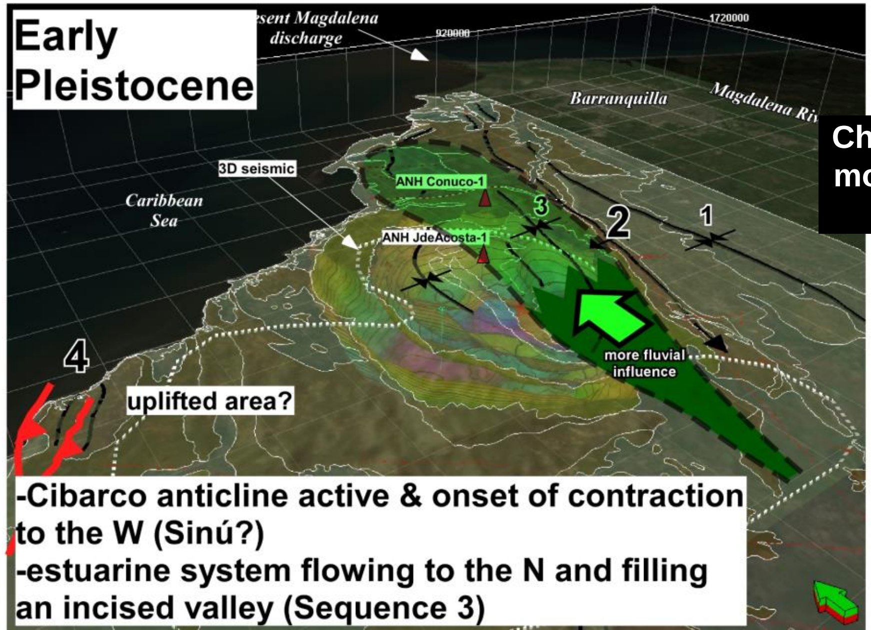
SB: sequence boundary
mfs: máximum flooding Surface
ts: transgressive Surface

3D evolution



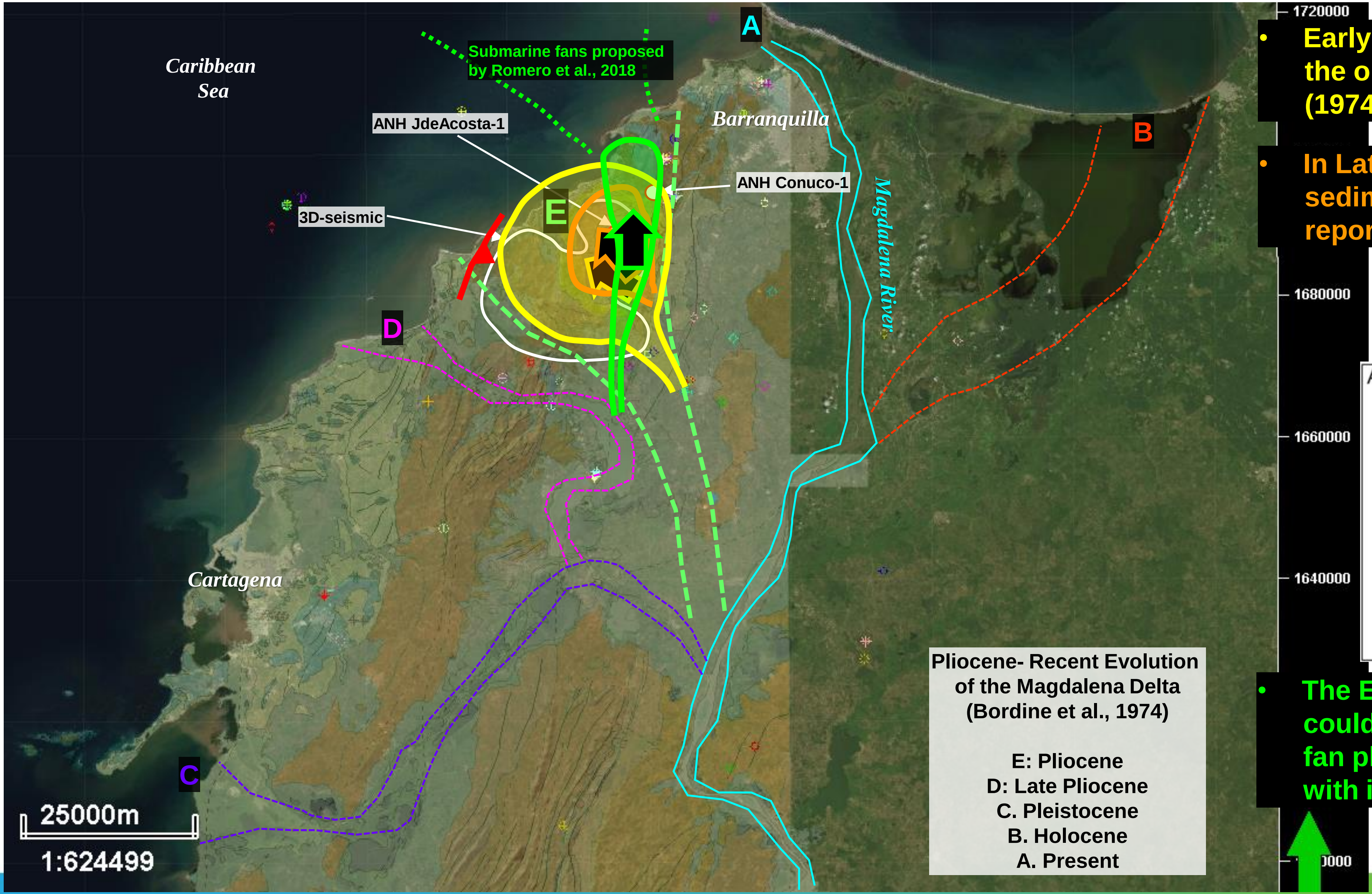


1. *Sabanalarga Syncline*
2. *Cibarco Anticline*
3. *Tubará Syncline*
4. *Sinú Fault system*

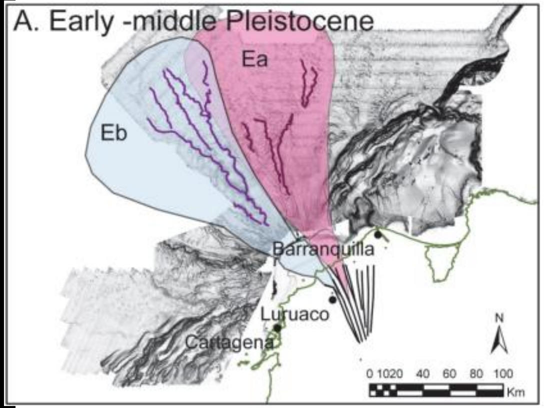


Chorrera (S3) changes to more marine facies to the North

Paleo-geography



- Early Pliocene delta system (S1) represents the oldest delta proposed by Bordine (1974, phase E)
- In Late Pliocene times (S2), deeper marine sedimentation with volcanic influence is reported for the first time in the study área



- The Early Pleistocene estuarine system (S3) could relate to the Ea and Eb, submarine fan phases proposed by Romero et al., 2018, with its river mouth close to P. Colombia

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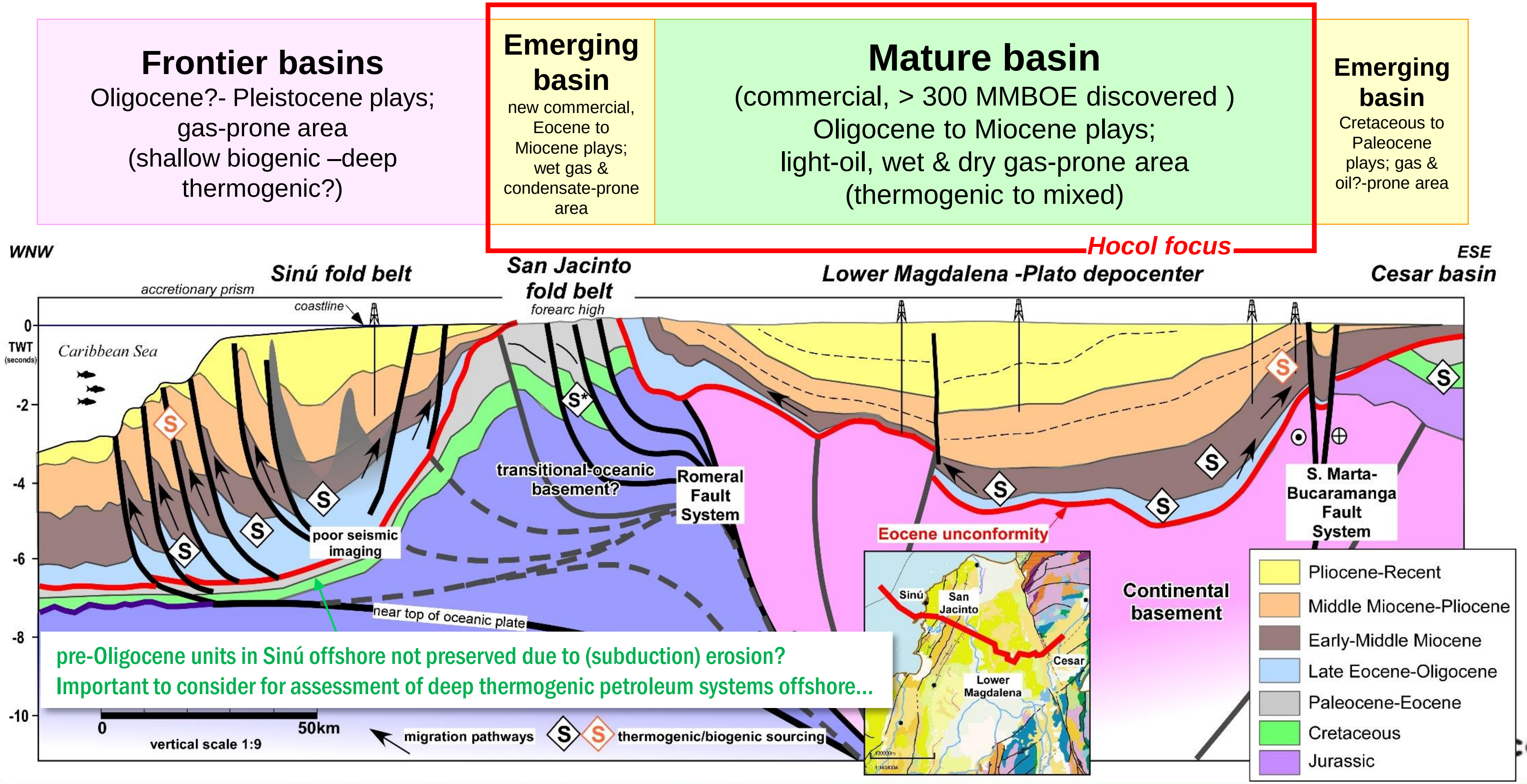
Conclusions

- The TJAS was filled by three unconformity-bounded sedimentary sequences of Pliocene to Early Pleistocene age, represented by four lithostratigraphic units.
- The lowest, Early Pliocene sequence is formed by two lithostratigraphic units, a basal unit comprising deltaic sandstones (Tubará Fm.), overlain by a finer-grained transgressive unit (Saco Fm.), and it was cored in the ANH Conuco-1 well.
- The middle, Late Pliocene sequence was cored in the ANH Juan de Acosta-1 stratigraphic well, comprising fining-upwards, slope & outer shelf deposits and evidencing a deepening of the basin (Juan de Acosta Fm.).
- The upper stratigraphic sequence, preserved in the axis of the TJAS, consists of an estuarine system which filled an incised valley (Chorrera Fm), exhibiting a change to more marine facies from S to N.
- A combination of biostratigraphy and U-Pb detrital zircon geochronology allowed us to better constrain the age of the stratigraphic section in the TJAS as Pliocene to early Pleistocene (4.7 -2 Ma), indicating that the arrival of the proto-Magdalena River occurred in early Pliocene times.
- The paleo-drainage of the Magdalena River changed from a SE-NW direction in early Pliocene times, to a S-N direction in early Pleistocene times, and such shift was probably due to the continued growth of the Cibarco Anticline to the E and by the contraction of structures towards the W (Sinú F.S?).

Implications for hydrocarbons

- The results of this work are key for basin and petroleum system modeling in the study area (complex deformation and infill).
- Understanding of sedimentary provenance and aid to carry out source to sink studies of sedimentary systems, which are crucial for exploration in adjacent offshore areas, that were fed by these deltaic and estuarine sedimentary systems.

The study area has not been as intensely exhumed as observed in the rest of the San Jacinto fold belt, allowing us to link the source areas in the continental interior, to the sink areas in the Sinú accretionary prism.



Ackowledgements

Thank you!

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