The fracture patterns of the Tin Tin anticline: Fracturing process during the foreland evolution in the Calchaquí Valley, northwestern Argentina

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Image obtained from Andbeyond.com. (2018). Calchaquí Valley and Cafayate winery trip in Salta| and Beyond. [online] Available at: https://www.andbeyond.com/experiences/south-america/argentina/salta/calchaqui-valley-cafayate-winery-trip/ [Accessed 10 Dec. 2018].

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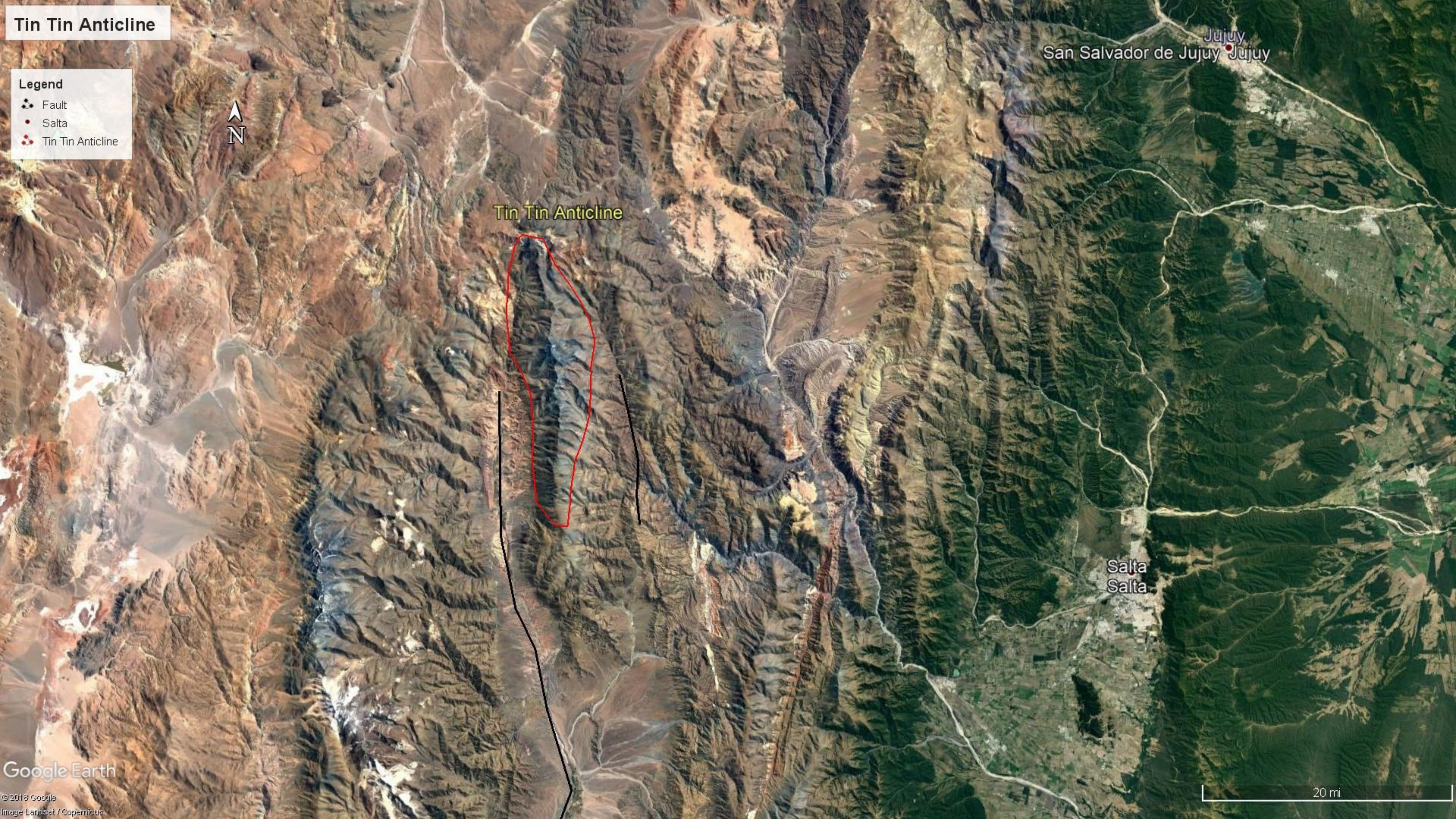
GEOL.5200: *STRUCTURAL GEOLOGY*

Outline

- Introduction
- Structural Stratigraphy
- Data collection
- Results
  - Extension fractures
  - Other mesostructures
- Conclusions

Introduction

- Study focused on the fracture patterns of the carbonate-silicoclastic Yacoraite Fm. In the Tin Tin anticline – a fault-related fold in southern part of the Eastern Cordillera in northwestern Argentina.
- Study of small-scale structures emphasize the importance of managing the naturally fractured reservoirs of folds and thrust belts
- In NW Argentina much of the hydrocarbon is trapped in the naturally fractured rocks of the Yacoraite fm. → economic potential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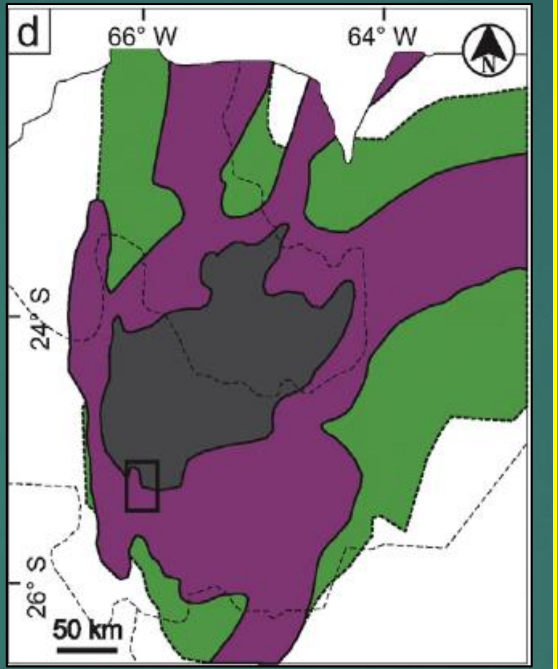
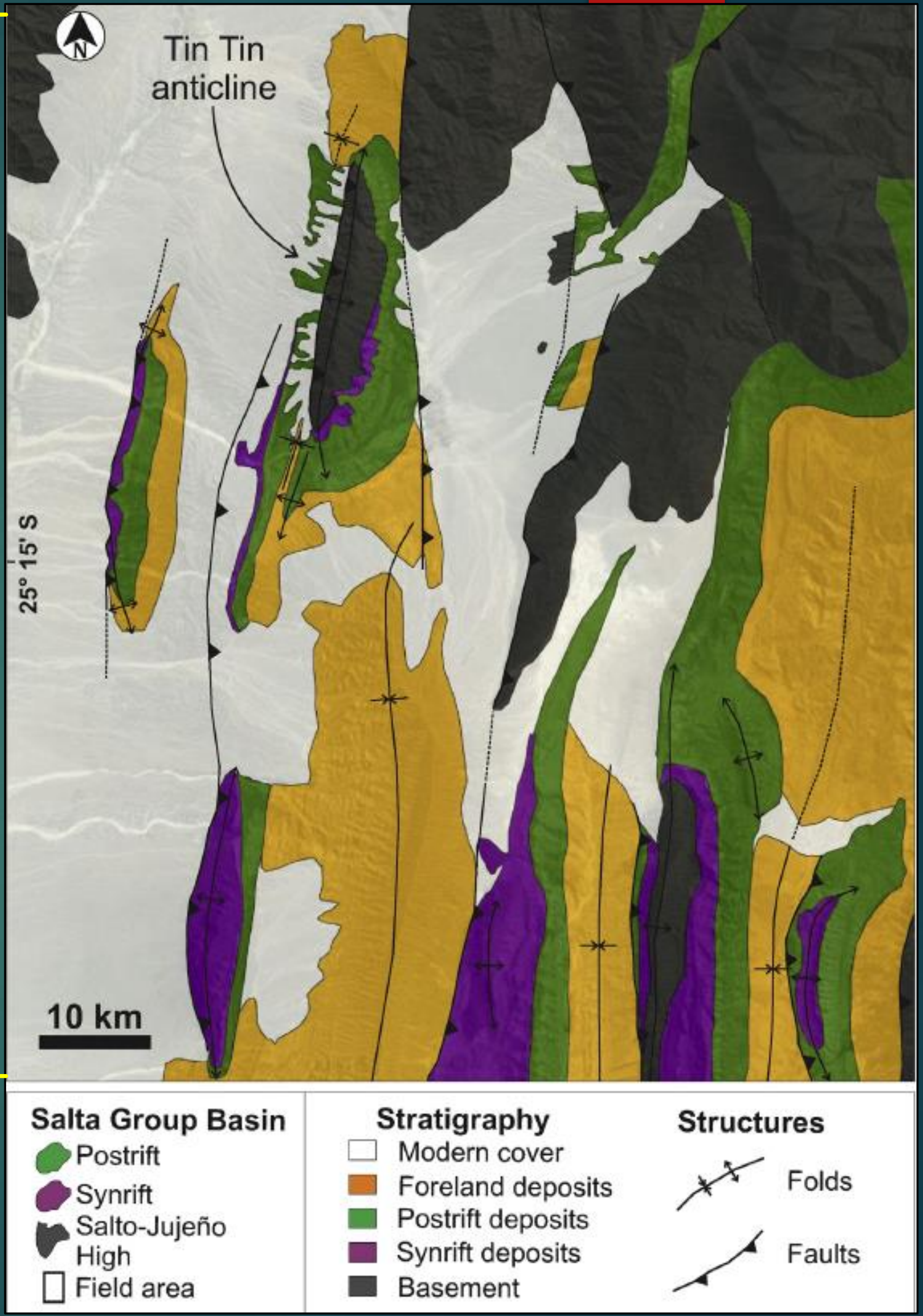
Structural history and Stratigraphy

- The Calchaqui Valley consist of a series of N-S-oriented valleys that extends between the Puna and the Eastern Cordillera.
- Area characterized by broadly N-S-striking and west vergent fault-related folds surrounded by basement blocks
- This framework is extensively assigned to the tectonic inversions of the Salta Group basin → resulted from Cenozoic Andean contraction



Figures 1d and 1b, modified from (Hernández and Franzese, 2017)

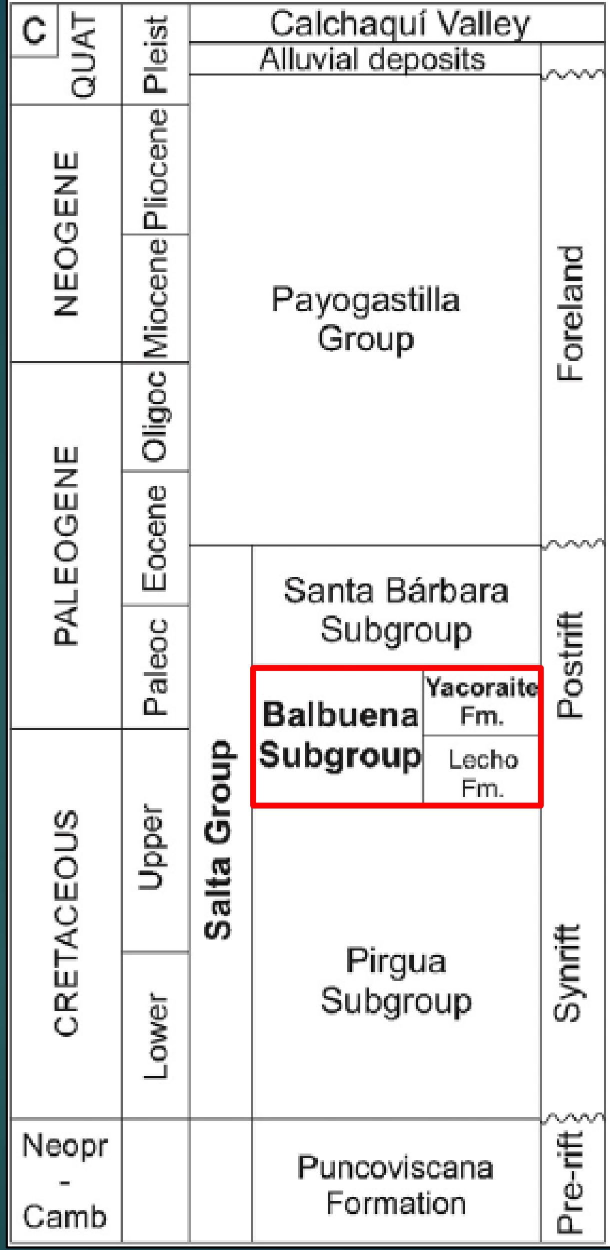


Structural history and Stratigraphy

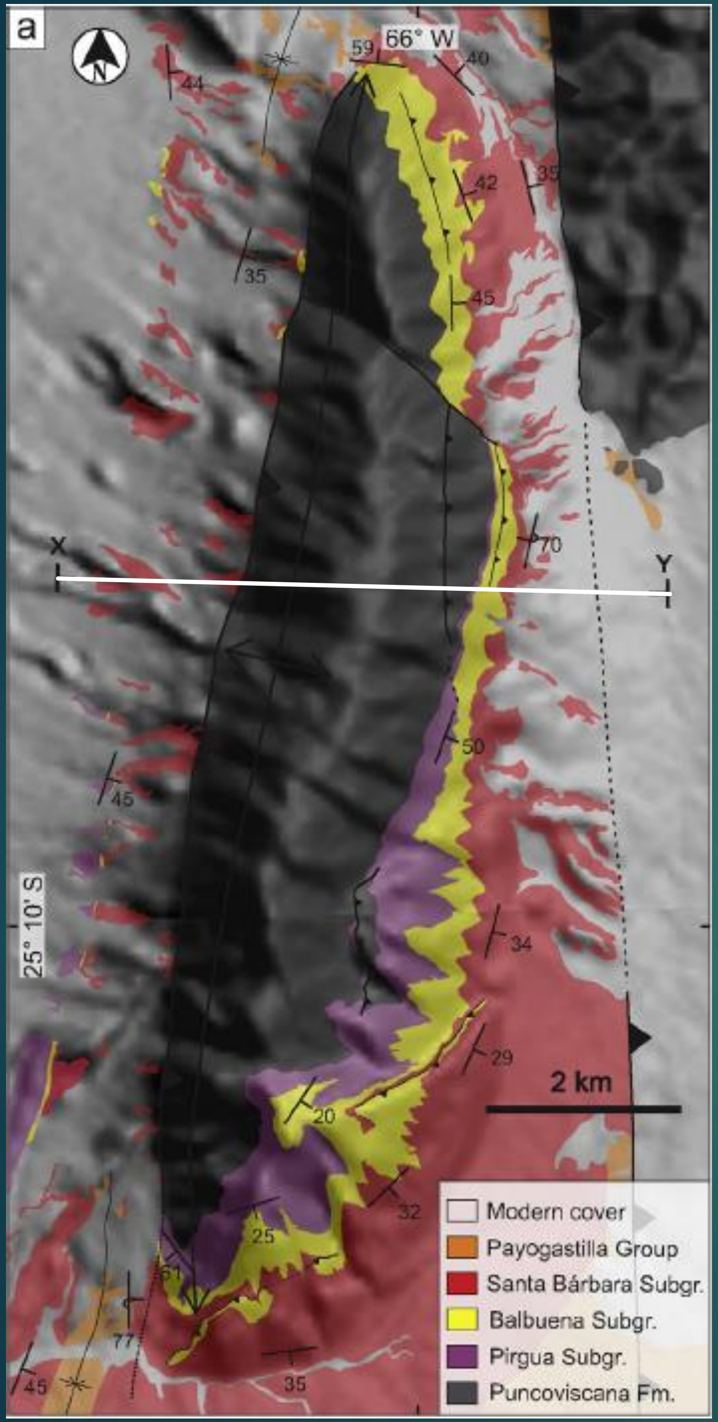
- Salta group basin → Rift-related
- Extensional phase during lower-Cretaceous and Paleogene
- Resulted in isolated grabens and sub-basins
- These sub-basins were then placed around a structural basement high → Salto - Jujeno High
- Pirgua subgroup (synrift) overlain by Balbuena subgroup (postrift)

  In response to decreased tectonic subsidence and relative sea-level rise → shallow Atlantic marine ingression

- Late postrift stage of basin (Santa Barbara subgroup) also related to thermal subsidence, but during drier climate
- Andean contraction during Paleogene → resulted in foreland basin filled by Payogastilla Group in the Calchaqui valley
- Finally tectonic inversion of the Salta Basin

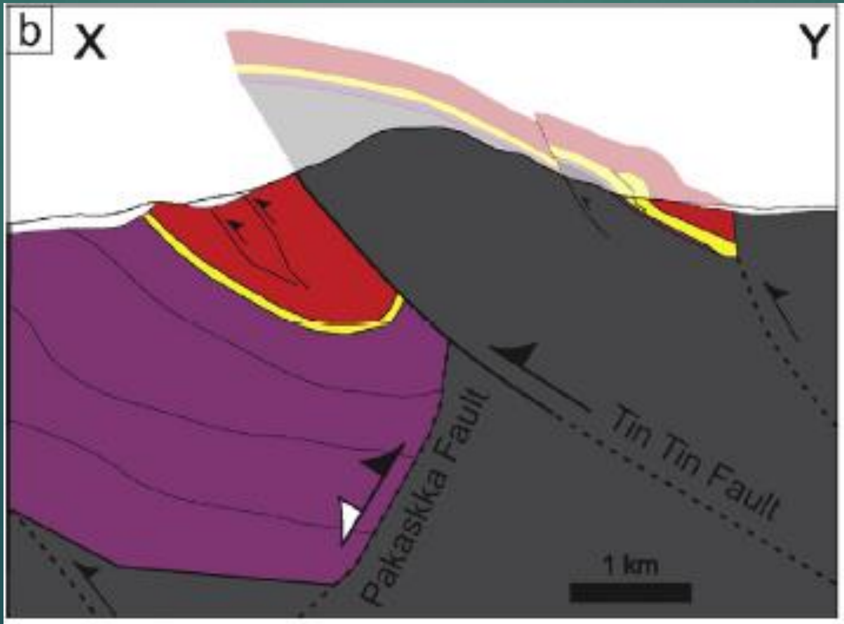


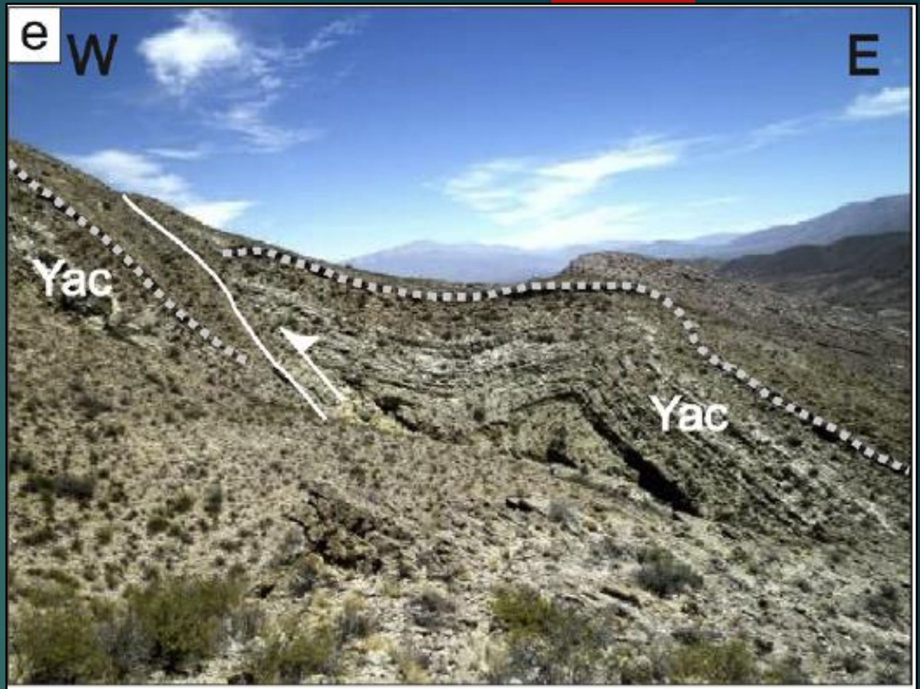
Figures 1c, modified from (Hernández and Franzese, 2017)

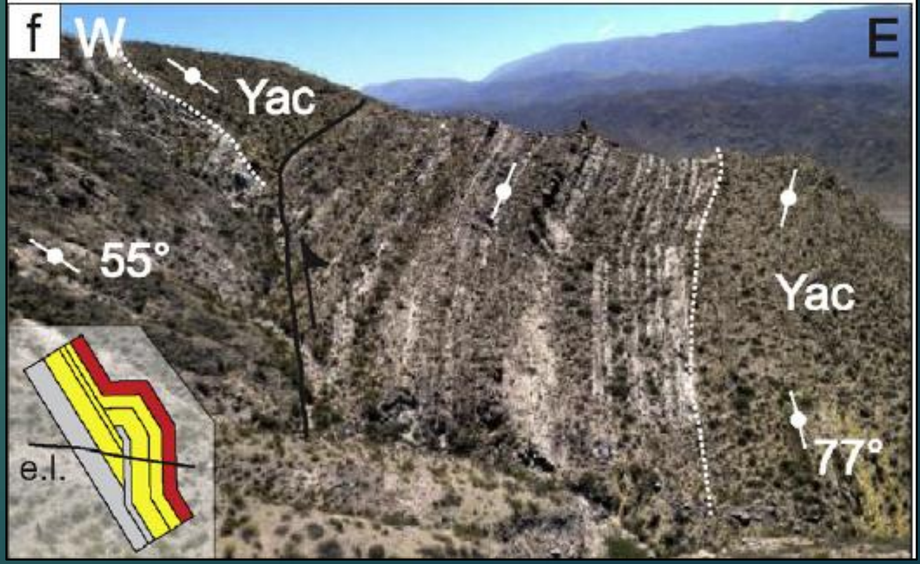


Structural history and Stratigraphy

- NNE-SSW striking, double-plunging, west-vergent anticlinal fold
- Fault propagated fold in response to the Tin Tin thrust





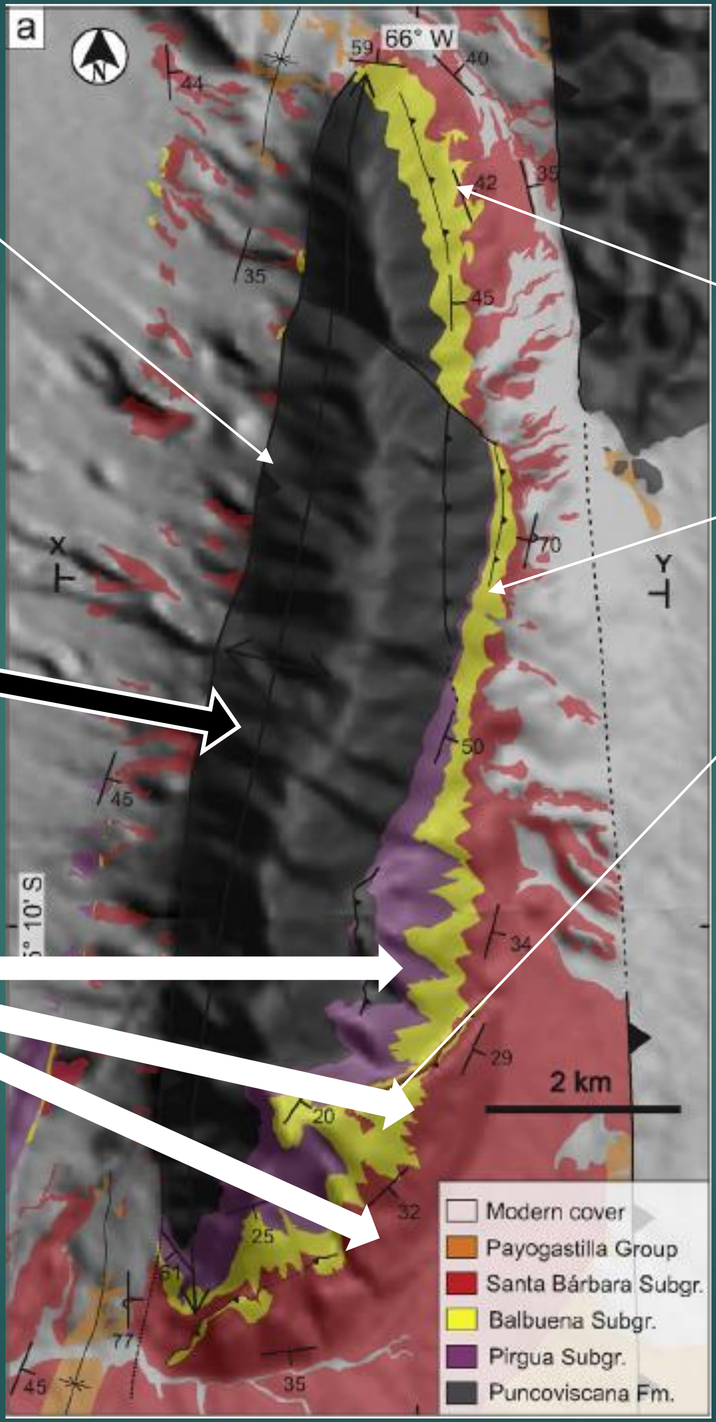


Figures 2, modified from (Hernández and Franzese, 2017)

Western limb:
More isolated and highly strained

Precambrian-Cambrian basement core: Metamorphic

Rift-related Phanerozoic sedimentary rocks



Backlimb and southern nose of the fold:
Sedimentary cover more exposed

Sedimentary cover was internally deformed shortly before and during Uplift.

Structural history and Stratigraphy

- The study will focus on the early post-rift Yacoraite sequence of the Salta Group.
- Santa Barbara subgroup also included due to similar mechanical behavior

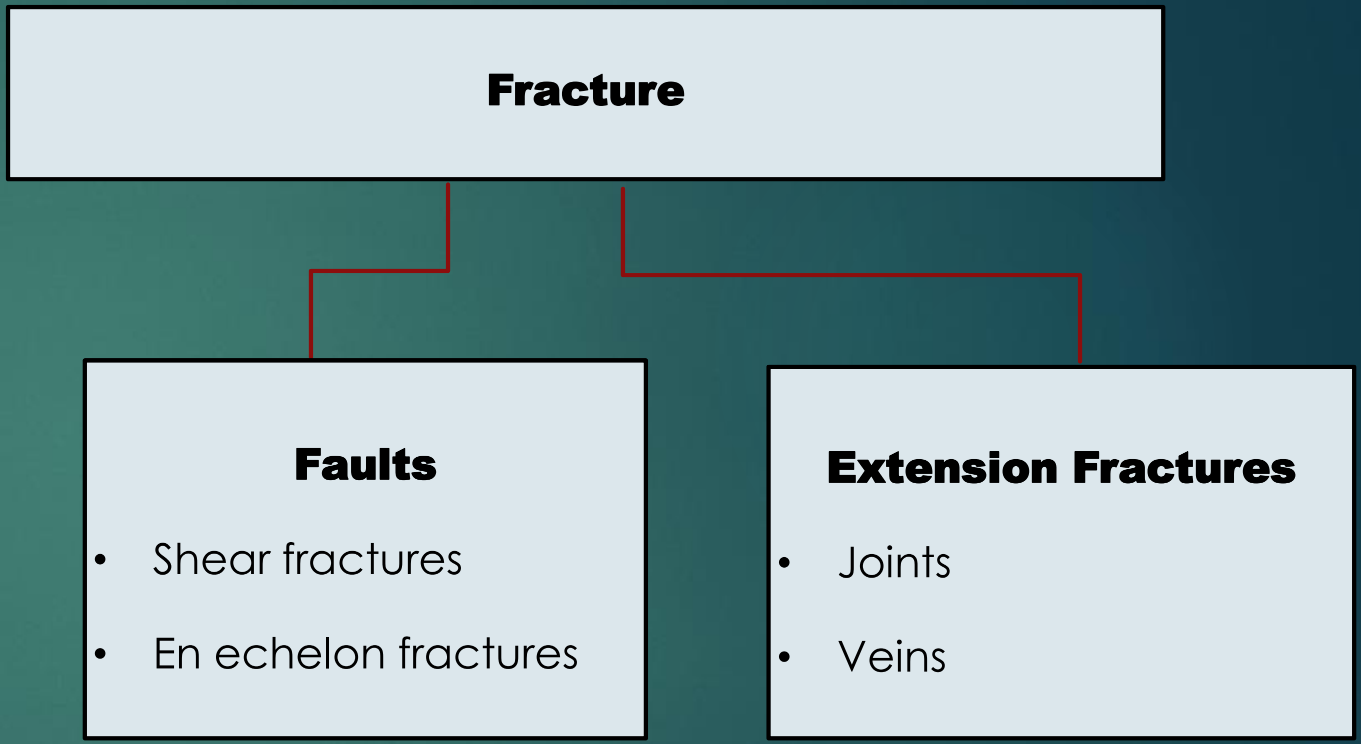
Yacoraite Formation

- Thickly bedded alternating sedimentary sequence of carbonate – siliciclastic rocks
- Contains cm to 1.5m thick beds of:
  - Limestone
  - Sandstone
  - Stromatolitic boundstones (mainly in upper sections)
  - Pelites
- Entire sequence is 57 meters thick at the Tin Tin anticline
- HOWEVER, thrust faulting thickened the unit up to 90 meters (only some parts of Backlimb)

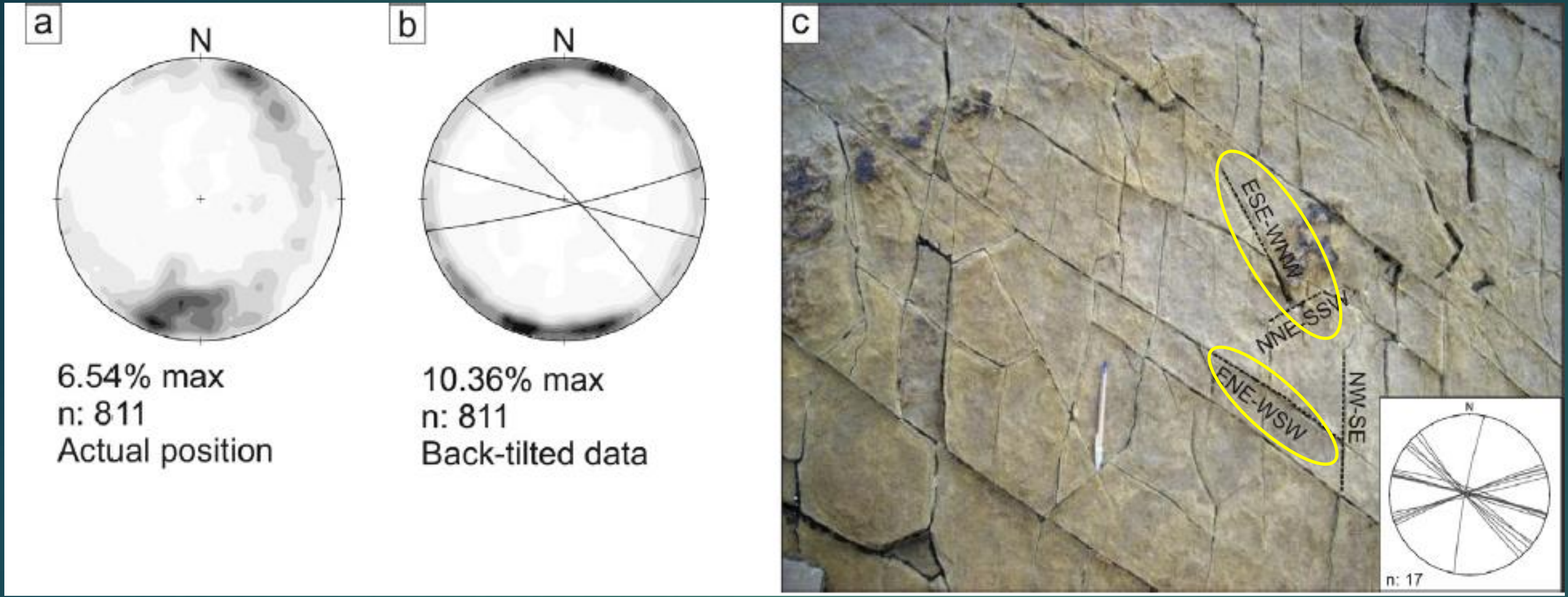
Diffuse bedding caused by high brittle strain

Data collection

- Field approach to:
  - Measure small-scale fractures in outcrops and grouping them in different sets based on
    1. Fracture types
    2. Orientation
    3. Relationship to other fractures and structural features
- Most data was obtained from the Backlimb where scan lines were performed
- Measured over 800 fractures
- Fractures data was back-tilted around a horizontal axis parallel to the local strike of bedding



Results



- Most fractures perpendicular to beds or disposed at high angle to bedding

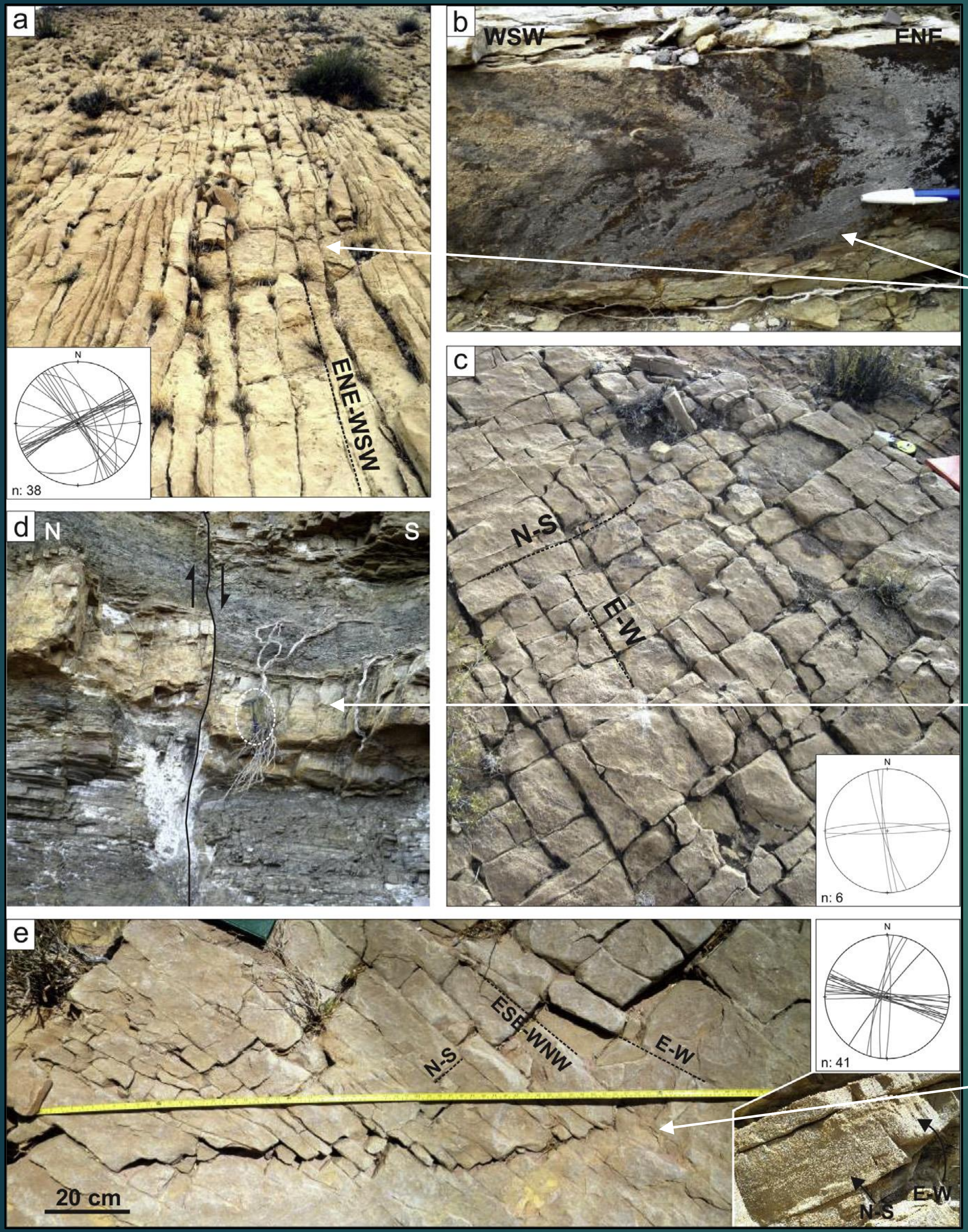
A: Present orientation (folded)

B: Bedding dip removal (unfolded data – considering each dip domain)

C: Representative outcrop with common fracture sets

- Two high-frequency groups observed, forming a broadly ***oblique or ladder pattern***
- At high angle to bedding

Extension Fractures: Joints, veins and normal faults



- Cm- to –meter long, bed-perpendicular and planar joints with plumose structure on the surface
- Exhibit ladder pattern
- Strikes from ENE to ESE
- Generally they bordered by shorter NNW to NNE cross-joints
- Distributed evenly along the anticline

E-W striking, high angle to bedding fractures with normal displacement are also present

N-S-trending fractures are absent at hinge zone, which is what one would expect in a folded layer.

Shear Fractures: Mesoscale strike-slip and thrust faults

- Strike-slip faults composed of bed-perpendicular, cm-m scale, roughly planar fractures and *en echelon* vein arrays (to lesser extent)
- **A:** Dextral & Sinistral strike-slips represented by shear fractures and en echelon vein arrays
- **B:** Conjugate en echelon vein array
- **C & D:** ENE-striking dextral fault (fracture array and vein array)
- **E:** ESE-striking Sinistral en echelon vein array

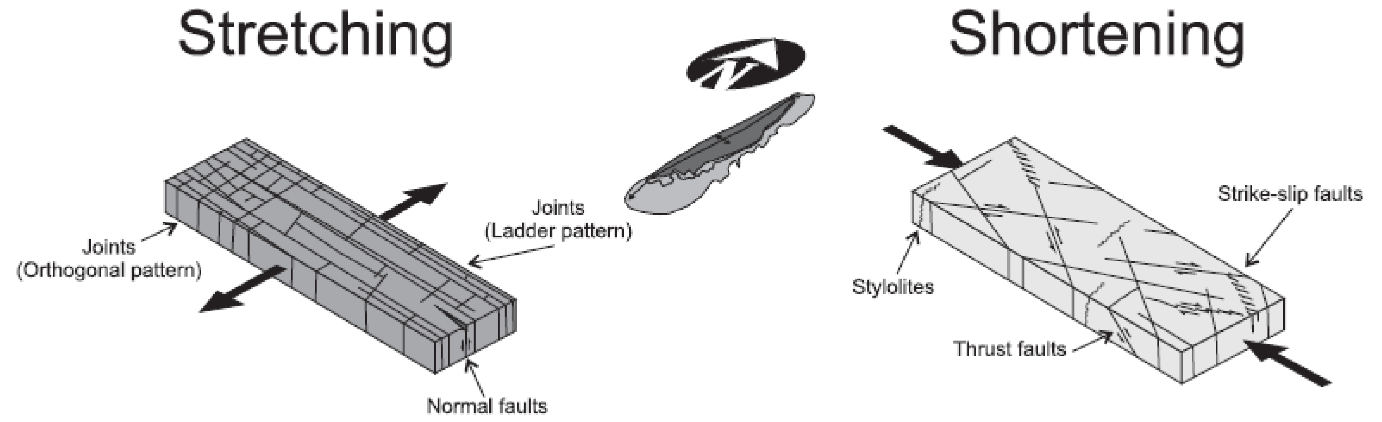


Fig. 8. Schematic diagrams of the fracture patterns in Tin Tin anticline. Left: transverse extension fractures formed by ~ N-S stretching. Right: Contractional mesostructures (small-scale faults and stylolites) formed by E-W to ESE-WNW shortening.

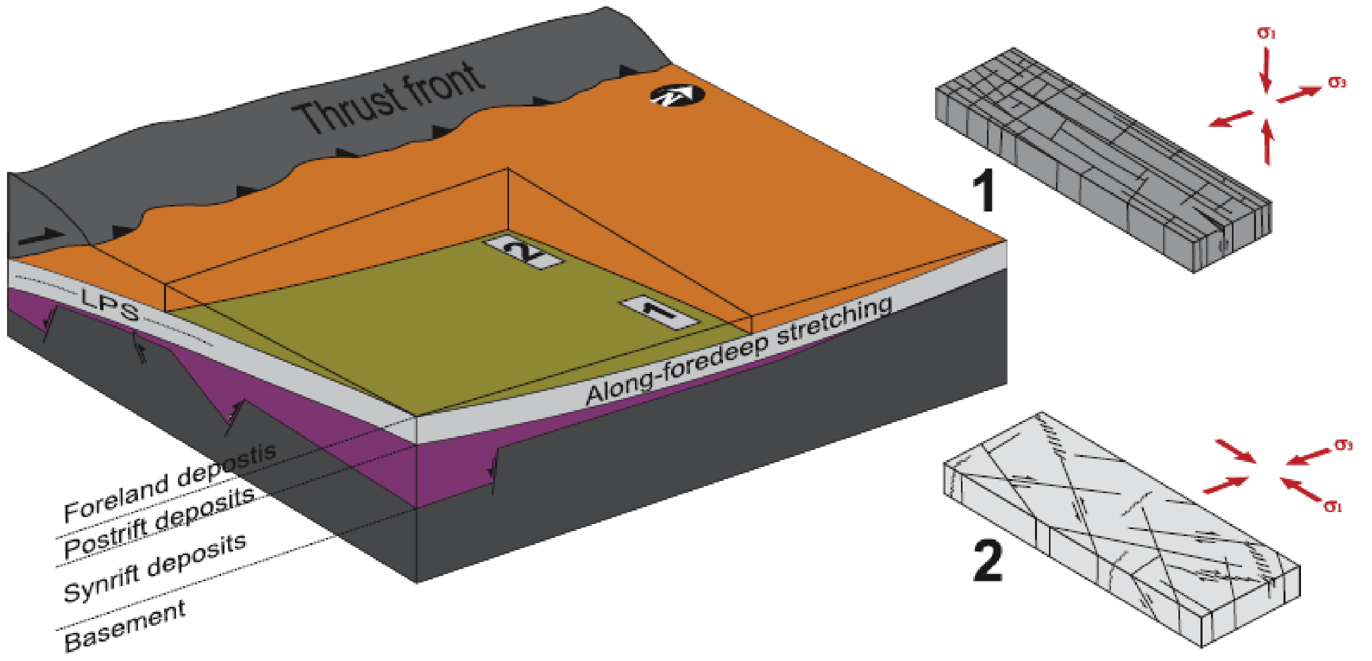
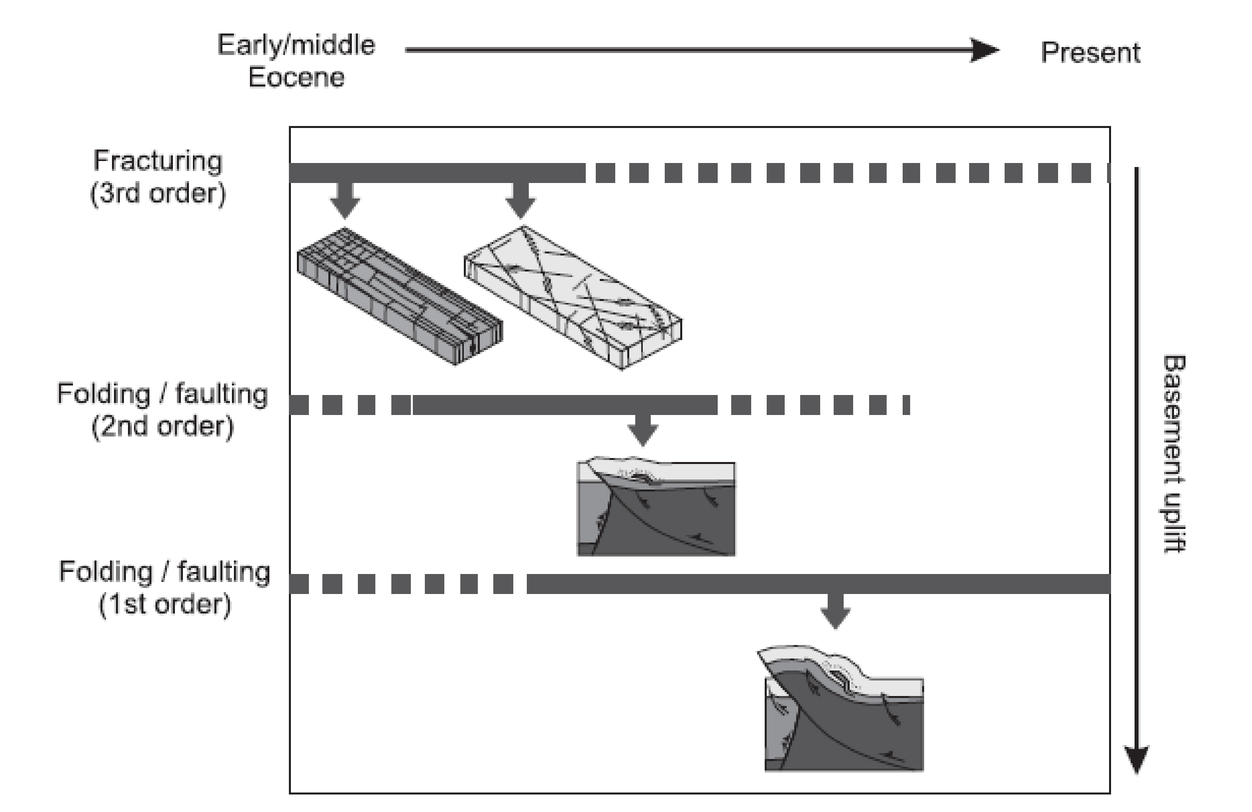


Fig. 9. Block diagram representing the Eocene thrust belt-foreland system and the occurrence of fractures. Extension fractures located in the belt-parallel stretched foredeep. Contractional mesostructures located near the thrust front, where layer-parallel shortening prevail. The orientation of the maximum and minimum principal stresses for each case is indicated.

Conclusion

- Mesoscale fractures in the Yacoraite Fm. in the Tin Tin anticline = joints, veins, small-scale strike-slip faults + less significant stylolites and normal faults
- These features are related to thrust belt-foreland basin system that was constructed during Eocene times at the onset of the Andean contraction.
- Extension fractures developed in response to N-S directed stretching
- Small-scale faults and stylolites formed during succeeding ESE-WNE layer-parallel shortening
- All fractures formed prior or during the infant stages of folding and faulting which led to the tectonic inversion of the Calchaquí Valley



Conclusion

- Naturally fractured reservoirs are often related to anticlinal formation
- However, this study revealed that not all fractures found in folded strata are a consequence of the folding events
- Thus, fractures were present prior to folding.
- The study also high-lighted that pre-folding fractures may play a vital role in secondary fracture development during the fold evolution → changing or inhibiting classical folding-related deformation patterns

↑

"This statement must be taken into account regarding the potential implications of the hydrocarbon exploration and production, focusing on the naturally fractured reservoirs of NW Argentina." - Hernández and Franzese, (2017)

References

- Hernández, M. and Franzese, J. (2017). The fracture patterns of the Tin Tin anticline: Fracturing process during the foreland evolution in the Calchaquí Valley, northwestern Argentina. *Journal of Structural Geology*, 96, pp.54-64.