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

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Outline

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- 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.
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 ingestion
- Late postrift stage of basin (Santa Bárbara 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

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

Precambrian-Cambrian basement core: Metamorphic

Rift-related Phanerozoic sedimentary rocks

Sedimentary cover was internally deformed shortly before and during Uplift.
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)
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.

Fracture

Faults
- Shear fractures
- En echelon fractures

Extension Fractures
- Joints
- Veins
Results

A: Present orientation (folded)

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

C: Representative outcrop with common fracture sets

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

• 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-slip 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 microstructures (small-scale faults and stylolites) formed by E-W to ESE-NNW shortening.

Fig. 9. Block diagram representing the Eocene thrust belt-fan system and the occurrence of fractures. Extension fractures located in the belt-parallel stretched foredeep. Contractual microstructures located near the thrust front, where layer-parallel shortening prevails. 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
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 highlighted 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)