**Structural Controls on the Evolution of Los Monos Anticline (Subandean Zone, Bolivia): Evidences From Surface, Sub-Surface Data and Kinematic Modeling**

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**Abstract**

Los Monos Anticline is a N-S trending, tightly folded anticline outcropping along the Aguaragüe range in the Subandean belt of southern Bolivia. The complexity of the structure and the poor quality of the seismic profiles in the area make the interpretation of the folded structures in the core of the anticline a difficult task. Consequently, it is necessary to aid the process of seismic interpretation through the use of kinematic modelling, structural techniques, and all available analogs in the Subandean region of Bolivia. Our work presents the process of developing a conceptual structural model applied to the main structure in the study area, Los Monos Anticline, considering key observations from surface, subsurface data, and kinematic modelling. Different structural styles have been tested; a combination of fault-bend and fault-propagation fold models seem to best characterize the structural style and evolution of the anticline. Structural restoration was also used to check and validate the interpretation of key seismic lines within the area of interest. Three balanced cross-sections have been constructed: the shortening estimates and structural evolution derived from the sequential restoration allows us to understand the structural controls on the formation and evolution of Los Monos Anticline. Pervasive internal shear and folding within the Intermediate décollement (Los Monos Formation) controls the accommodation of shortening in the structure. The Main Basal Silurian Detachment controls the Lower Devonian units’ deformation generating an Overlapping Ramp Anticline geometry that characterized the core of the anticline. The evidence of four-way dipping closures of the structure generates an exploration interest to investigate these deeper formations as potential gas reservoirs in the region.

**References Cited**


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Introduction and Regional Setting

- The Serrenta Aguaragüe Centre is located in the Subandean Zone of Bolivia, within the Department of Taraco, and is part of the Eastern Foreland Basin of the Andean Cordillera.
- The complex geology and different structural styles identified in the area, limit the ability to acquire and process seismic data.
- The general structure is characterized by trends of fields with 100's km of lateral continuity across the border from southern Bolivia into northern Argentina.

Workflow

- Lithostratigraphic Sequence:
  - Biostratigraphic data
  - Sequence stratigraphy
  - Stratigraphic data
  - K-Ar and Ar-Ar dating
  - Detrital zircon U-Pb dating
  - Stable isotope data
- Sequence Interpretation:
  - Nappe stacking and stacking thickness
  - Sequence stratigraphy
  - Stratigraphic data
  - K-Ar and Ar-Ar dating
  - Detrital zircon U-Pb dating
  - Stable isotope data
- Interpretation of Seismic Sections:
  - Velocity of seismic reflection
  - Interpretation of seismic reflection
  - Sequence stratigraphy
  - Stratigraphic data
  - K-Ar and Ar-Ar dating
  - Detrital zircon U-Pb dating
  - Stable isotope data
- Structural Interpretation of Shallow Domain:
  - Fold geometry
  - Structural interpretation
  - Sequence stratigraphy
  - Stratigraphic data
  - K-Ar and Ar-Ar dating
  - Detrital zircon U-Pb dating
  - Stable isotope data
- Forward Modeling
  - Structural modeling
  - Sequence stratigraphy
  - Stratigraphic data
  - K-Ar and Ar-Ar dating
  - Detrital zircon U-Pb dating
  - Stable isotope data
- Correlation of Existing Wells:
  - Correlation of seismic sections
  - Sequence stratigraphy
  - Stratigraphic data
  - K-Ar and Ar-Ar dating
  - Detrital zircon U-Pb dating
  - Stable isotope data

Results

- The geometry of Los Monos Anticline changes along strike, verging westward to the north and verging eastward to the south of the study area.
- The fold axis dips towards the north, for a distance of less than 20 km of distance along strike.
- Considering the stratigraphy and seismic data, the outcropping Aguaragüe and Los Monos faults, are detected in Los Monos Fm. The thickness variation of the mapping units is related to the significant deformation during fold development.
- Faults 1 and 2 controlled the development of the foreland directed duplex below Los Monos Fm, displaying more displacement towards the south of the area (Section 03).
- The interpreted fault-related folding below Los Monos Fm in the core of the anticline is controlled by the Skirak fault (Kharaq Fm). This basal detachment level has been interpreted at depths ranging 8.5 to 9 km, with a regional dip of 2° towards the hinterland.

Discussion

- The change in vergence of Los Monos Anticline from north to south, is related to increasing shortening towards the south.
- According to the forward models, the angle of the ramp which generates the fault-fold belt geometry controls the backlimb of the resulting anticline in the Lower Sequence (Skirak-Lower Devonian units) and could potentially determine as well the evolution of the breakthruh faults detaching at the base of the Los Monos Fm (Intermediate detachment level).
- Los Monos Anticline at depth can be interpreted as a complex overlapping ramp anticline composed by at least three levels of structural deformation, with a foreland directed sequence of thrusts detached on the Kharaq Fm (Skirak detachment level) and developing fault-bend fold geometries (Suppe, 1983).
- The units above Los Monos Fm, show a different structural style due to the faults breaking through the core and the backlimb of the anticline; fault-propagation folding may determine the overall geometry of this structural segment.

Structural Interpretation of Shallow Domain

- The fold geometry was constructed considering the fold axes orientations from external surface contacts between key units and well data. Dipmeter and formation tops of the two wells (Will-01 and Will-02) were used to perform the structural interpretation of the shallow domain.

Forward Modeling

- Forward modelling was carried out to propose new views about the structural evolution of the anticline.

Sequential Restoration

- Restoration of the Aguaragüe and Los Monos faults show that the intermediate detachment level at the base of the Los Monos Fm controlled both faults.
- Restoration in combination with the forward modeling for the Lower Sequence, showed that Los Monos Anticline initiated by thrusting detached at the base of the Kharaq Fm, followed by the generation of a duplex system that involves the Skirak and Lower Devonian units (Kharaq and Skirak formations respectively), leading to the formation of a foreland directed duplex geometry.

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References