4D Understanding of the Evolution of the Penal/Barrackpore Anticline, Southern-Sub-Basin, Trinidad, W.I.*

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Abstract

The Penal/Barrackpore Anticline is a subsurface southeasterly verging, detached middle Miocene frontal fold within the Southern Basin Trinidad, generated by the southeastward directed oblique collision of the Caribbean Plate/Accretionary Prism with the northward subducting South American Continental Crust. The oblique collision generated foredeep settings in the Southern Basin, into which the middle Miocene primary reservoir, upper bathyal Herrera sand turbidites were deposited in synclinal lows. The integration of well data, and semi-regional 2D seismic lines across the Southern Basin coupled to surface geology revealed at least three structural levels within the Penal/Barrackpore Anticline, namely, the Overthrust, Intermediate or Overturned limb, and Subthrust. Pliocene gravity-driven extensional tectonics produced numerous northwest- to southeast-trending, eastward-facing, curvilinear, detached normal faults which further dissected the structure. Pleistocene near-normal contractional/transpressional deformation resulted in refolding and retightening of structures producing Out-of-Sequence thrusts, backthrusts and mud diapirism.

4D evolution of the anticline, acquired by integrated restorations of 2D seismic lines and infill wells, revealed the growth of the anticline from a early Miocene detachment fold through to a middle to late Miocene tri-shear fault propagation fold. By combining the restored middle Miocene topography, restored Net Sand values and palaeo-bathymetry, sand depositional modelling of the primary reservoir was undertaken, revealing two major northeast-to-southwest sand trends and their unique relationship to growing structures. Zones with a high probability of thick sand deposits were forward modelled to their Present Day locations, evaluated and ranked based on the geometry and nature of the structural or stratigraphic trap, as well as the possibility of tertiary hydrocarbon migration due to Pleistocene deformation.

References


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Executive Summary

The syn-kinematic Middle Miocene Herrera deposits demonstrate the effect of oblique compression in an upper bathyal, east-facing turbidite foredeep. The growth of the NE-SW trending Penal/Barrackpore Anticline resulted in zones of absence of the Middle Miocene reservoir, eventually incorporated into the highly dissected, steeply dipping forelimb of the Present Day structure, which accommodated as much as 8km of NW-SE directed shortening. The anticline was further dissected by NE-SW to NW-SE gravity-driven detached normal faults during the Miocene, reactivating Middle Miocene syn-thrust extensional fault lines. Paleocene near-normal compression refolded the structure and produced southeast-easterly verging Out-of-Sequence thrusts anticlines and normal verging backthrusts associated with the NW-SE trending Las Bajos lateral ramp.

1.0 Introduction

The Penal/Barrackpore Oilfield is an onshore development field, situated within the Southern Sub-Basin of Trinidad, located approximately 10km south of the southern city of San Fernando (Bittelli et al. 1958, Hosen 1990, Dyer 1992 (Fig. 1)). The field comprises a dissected south-west plunging, south-east verging elongated middle Miocene anticline, at least 7km long and 5km wide, draped with gently folded, imbricate passive foredeep until upper Miocene to Recent cover stratigraphy (Dyer 1992, Hosen 1990). The field has been in production for over 100 years from Pliocene Wilson deltaline sands of the low amplitude, folded forest formation, with the main anticlinal structure discovered by exploration drilling in 1938 by Royal Dutch Shell in search of middle Miocene Herrera turbidite reservoirs with subsequent reservoir levels discovered in 1946, termed the intermediate zone, and deep test, onshore drilled in 1949 by Trinidad Leaseholders Limited, termed the Sub-deep (Higgins 1955, Bittelli 1958, Dyer 1990) (Fig. 4).

Figure 3: Regional Tectonic Map of Trinidad compiled by Pindell (2004)
2.0 Seismic Interpretation : Present Day 3D Model

- Miocene dissects
- Oligocene detachment
- Tri-shear
- Soloman Anticline
- Subthrust Formation

Main Extensional 1 - easterly, N to S trending normal/slip detachments
Main Extensional 2 - westward, N to S trending normal/slip detachments

2.1 Restoration

- Tri-shear "Move on Fault" reverse modelling of the growth of the Penal/Barrackpore Anticline
- Miocene dissects
- Oligocene detachment

2.1.1 Restoration steps:

1. Present Day Seismic Interpretation Line 185
2. Seismic Interpretation of dip-oriented Line 177 highlighting southeast fold
3. Seismic Interpretation of dip-oriented Line 185 highlighting north verging Backthrusts
4. Map view of displayed SBC 2D Seismic Sections
5. Seismic Interpretation of strike-oriented Line 151 highlighting extensions/seaward
6. Present Day 3D Model of Primary Reservoir Middle Miocene Gr7hc showing zones of absence
7. Middle Miocene Herrera Gr7h & The sands were syn-sedimentary - deposited in synclinal lows on detachment folds I iddle Miocene Gr7d/Herrera surface.
8. Zones of salt absence coincide with I iddle Miocene Gr7d palaeo-highs - supported by the diapiric shape of the zones of absence, as well as the presence of thick sands to the north and south, gradually thinning onto the anticlinal crest.
9. Miocene-Leonie contractional deformation accommodated in Out-of-Sequences Doby/Wellington and Back Dome Anticlines to the north and south of the Penal/Barrackpore Anticline, and in north verging backthrusts possibly due to the thinning out or facies change within the underlying Cretaceous/ Jurassic anhydrite deccollement near the Present Day south coast of Trinidad (Figs. 9 & 10).
10. The Penal/Barrackpore Backthrust - offset of 214 ms TWT (~65m) on Line 174, to 445 ms TWT (~115m) on Line 180 (5km to SW) (Fig. 8).
11. Miocene-Leonie contraction utilized the Penal/Barrackpore Backthrust, folding crest stratigraphy, and producing a surface antimonial expression to the north of the south-dipping anticlinal trend.
12. Solomon Anticline dissected by stacked north verging backthrusts as it plunges into the NW-SE trending Less Blues Lateral Ramp.
3.0 Restored Surfaces - 4D Evolution of Penal/Barrackpore Anticline

The NE-SW trending main anticlinal structure (6km long, 1.3km wide). Minor foreland propagating fold (3.4km long, 1.3km wide). Relative amplitude of 25-75ms TWT (76-230m), with subtle SW vergence.

3.1 Middle Miocene Gr7bc Sand Deposition Modelling

Well Data Constrained Middle Miocene Gr7bc Net Sand Map
- Two NE-SW sand trends (Fig. 22).
- North Sand Trend: a thick (~150m) confined (12km long, 2.5km wide) body.
- South Sand Trend: a thick (300-400ft) thinning southward (150-200ft) less confined (9km long, 3km wide) body.
- Anticlinal Axis correlates with NE-SW trending zone of absence/decrease in sand.
- A narrow sand trend (6km wide, 2.5km long) orthogonal to the anticlinal axis connects the north & south trends.
- This demonstrates spillage from northern perched sand accumulations to the south with the southeastern advancement of the deformation front.

3.2 Vector Map
- The Middle Miocene Gr7bc Vector model was calculated by comparing the Present Day and Restored Middle Miocene Gr7bc surface coordinates, and plotting the in-plane net shortening on the Restored Middle Miocene Gr7bc surface.
- The Vector Model shows that most shortening was accommodated in the north eastern part of the Study Area - maximum values of 8km, decreasing to the southwest, with values of less than 3km (Fig. 23).
- A NW-SE trending narrow elongated zone of reduced shortening labelled A separates zones of greater shortening labelled A & B.
- This zone coincides with the possible tear fault named Main Extensional 2 and quantifies the in-plane impact of the tear fault on the distribution of shortening within the Study Area (~1.5km).

3.3 Forward Modelling & Ranking of Prospects

Simulated Middle Miocene Gr7bc Net Sand Map (Fig. 20)
- Herrera Fan Lobe 25-30km long x 20km wide.
- North Sand Trend thickness to SW along 400m bathymetric contour.
- South Sand Trend; thick sands occur on south facing limb of syncline and continue seaward due to widening of syncline by west facing tear fault, along 500m bathymetric contour.

Middle Miocene Restored Gr7bc Herrera
- NE-SW trending main anticline (6.5km long, 2.5km wide) with SE vergence.
- Relative amplitude of 50-75ms TWT (150-230m), early stage fault propagation fold.
- Synclines: 5km wide, 10km long of 50-125ms TWT (150-300m) amplitude.
- Synclinal axis shifted southward paralleling the structural relief.
- Significant NW-SE structural low - 250ms shallowing to 50ms TWT (765-150m) - tear fault.
- Zones of absence/reduced Gr7bc Herrera sands coincide with anticlinal crest.

The depositional pattern of the Gr7bc Herrera sands would have been considerably affected by the major structural relief feature. As sands spilled from the restricted northern syncline to the southern much broader syncline, the impact of structural relief on deposition would have been greatly reduced (Fig. 17).

Middle Miocene Restored Gr7a Herrera
- NE-SW main structural relief spanning 9km long, 3.3km wide with SE vergence.
- Relative maximum amplitude of 20-40ms TWT (62-122m).
- Structural lows subdivide and restricted, 20ms TWT (62m) amplitude (1km wide, 4km long).
- Fault propagation fold, gentle backlimb, steep forelimb, confined footwall syncline.
- Zone of absence of Gr7a Herrera sands more extensive than Gr7bc Herrera.
- Accommodation space for Gr7a Herrera far less than that of the Gr7bc Herreras.
- Rate of deposition of Gr7a Herrera kept pace with the tectonic growth of the anticline and its associated accommodation space (Fig. 19).