

PS Structurally Controlled Stratigraphic Traps within the HGOR Area, Palo Seco, Southern Basin, Trinidad*

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Abstract

The High Gas Oil Ratio (HGOR) area encompasses approximately 120 wells from both the Palo Seco and Central Los Bajos Fields. It was so nicknamed based on the uniquely high proportion of gas to oil recovered. The HGOR Area was developed between the 1960s and late 1980s, after which all drilling activity within the area ceased. During the 1990s, several EOR projects were undertaken with some success, however, they were discontinued based on some economic and technical difficulties encountered during the late 1990s and were not reactivated since. The HGOR Area produces oil and gas from predominantly the Pliocene Forest and Morne L'Enfer formations. The Pliocene Top Cruse marker was penetrated at quite shallow depths in some wells and although they were not always tested; the underlying Upper Cruse sands of the Pliocene Cruse formation revealed a significant resistive response. Based on this, a geological study of the Cruse formation (with special focus on the Upper Cruse sands) was undertaken using all available well data, and hydrocarbon maps were generated and analyzed. The results reveal that the traditional ideas of strike-slip tectonics may be easily challenged, as a compressional regime featuring thrust mechanics appears to dominate along the Los Bajos Fault System.

STRUCTURALLY CONTROLLED STRATIGRAPHIC TRAPS WITHIN THE HGOR AREA, PALO SECO, SOUTHERN BASIN, TRINIDAD.



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1.1 ABSTRACT

- ❖ The High Gas Oil Ratio (HGOR) area encompasses approximately 120 wells from both the Palo Seco and Central Los Bajos Fields.
- ❖ So nicknamed based on the uniquely high proportion of gas to oil recovered.
- ❖ Developed between the 1960s and late 1980s, after which all drilling activity within the area ceased.
- ❖ During the 1990s, several EOR projects were undertaken with some success, however, they were discontinued based on some economic and technical difficulties encountered during the late 1990s and were not reactivated since.
- ❖ The HGOR Area produces oil and gas from predominantly the Pliocene Forest and Morne L'Enfer formations. The Pliocene Top Cruse marker was penetrated at quite shallow depths in some wells and although they were not always tested; the underlying Upper Cruse sands of the Pliocene Cruse formation revealed a significant resistive response.
- ❖ Based on this, a geological study of the Cruse formation (with special focus on the Upper Cruse sands) was undertaken using all available well data, and hydrocarbon maps were generated and analyzed.
- ❖ The results reveal that the traditional ideas of strike-slip tectonics may be easily challenged, as a compressional regime featuring thrust mechanics appears to dominate along the Los Bajos Fault System.



1.2 INTRODUCTION

WHAT IS HGOR?

High Gas Oil Ratio (HGOR) is the term applied to recovered crudes featuring ratios greater than 1000 mscf/bbl, and API values >20°.

HGOR phenomena may occur as a result of:

- Early Stage: Solution Gas/Gas Cap Drive
- Evaporative Fractionation/Reservoir Compartmentalization
- Characteristic of Foamy Crude
- *Pressure differences near active fault zones...?*

HGOR AREA, SOUTHERN BASIN

The HGOR Area spans approximately 23 km², and is located at the intersection of the Palo Seco and Central Los Bajos Fields.

Study area (Fig 1) is 4 km² and consists of approximately 120 wells.

GOR_{avg}=5000

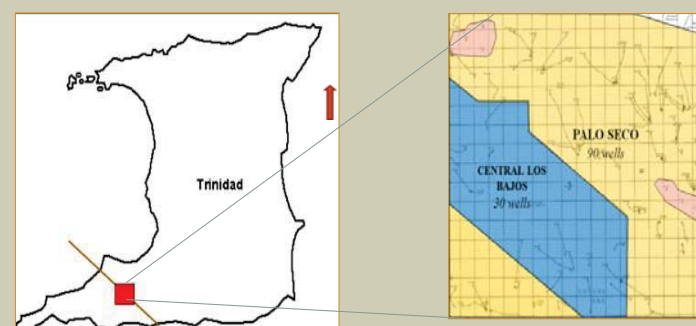


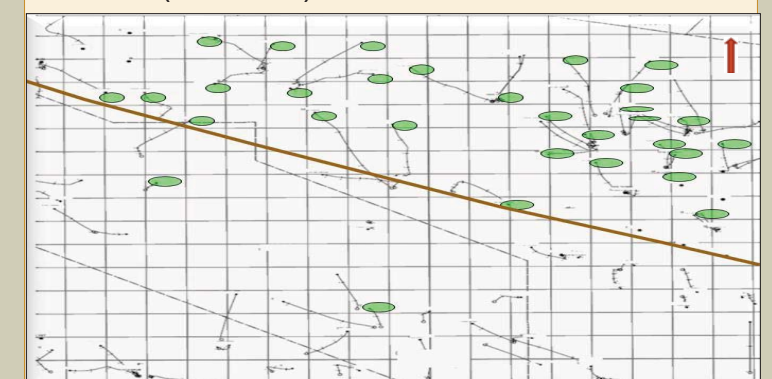
Fig 1 - Location of study area

PRODUCTION DATA

Formation	Cumulative Production (mmbbl)
Morne L'Enfer	2
Forest	2
Cruse	0.4

Production is maintained from:

➤ **Pliocene/Pleistocene Forest Fm** (North LB)



➤ **Late Miocene/Pliocene Cruse Fm** (South LB)

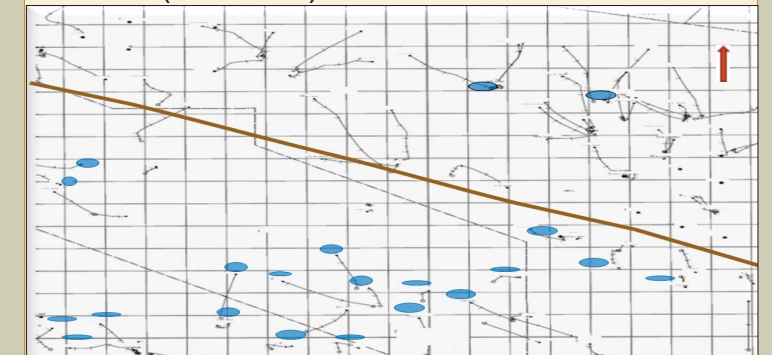


Fig 3 - Wells drilled to Cruse Fm

1.3 REGIONAL GEOLOGY

SURFACE GEOLOGY

- Late/Miocene Pliocene Cruse Fm, Pliocene/Pleistocene Forest and Morne L'Enfer Fms, Pleistocene Cedros Fm and Recent Alluvium Deposits featured at surface (Fig 4).
- Los Bajos Fault Zone runs through the study area, with smaller-scale normal fault splays (Skinner Fault and Santa Flora Fault). See Fig 4.

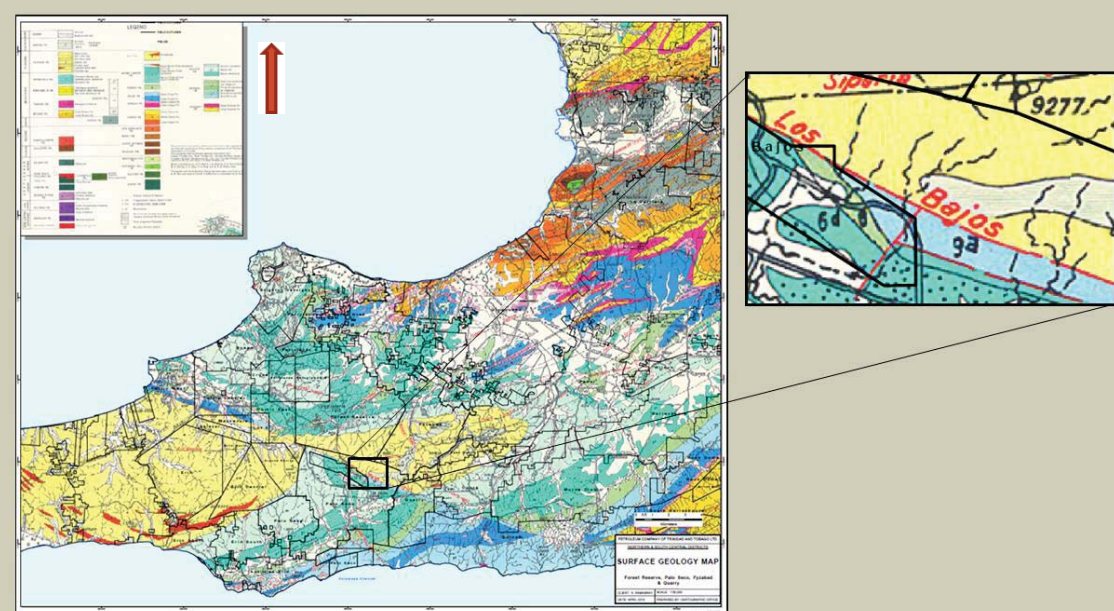


Fig 4 - Surface Geology map, highlighting HGOR study area (Kugler, 1959)

BIOCHRONOSTRATIGRAPHIC FRAMEWORK

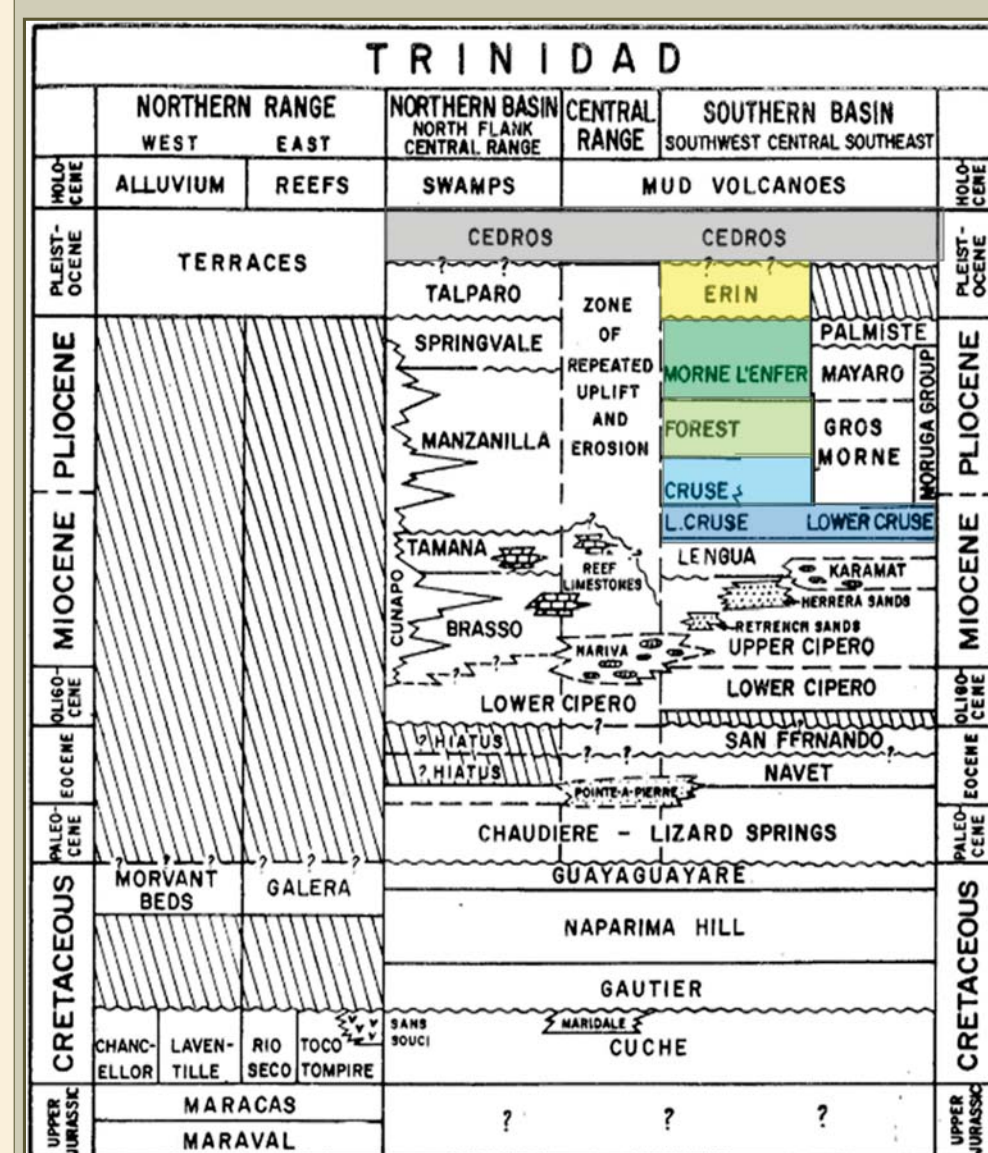


Fig 5 - Trinidad Stratigraphic chart (after Frampton and Carr-Brown, 1979)

TECTONOSTRATIGRAPHIC HISTORY

The Greater Trinidad Area is characterized by 3 major deformational phases (Ramlackhansingh, 2010):

1. Extensional Synrift Phase (Middle Jurassic 190-157 Ma)
2. Passive Margin Phase (157-60 Ma)
3. Active Margin Phase (65 Ma – present)

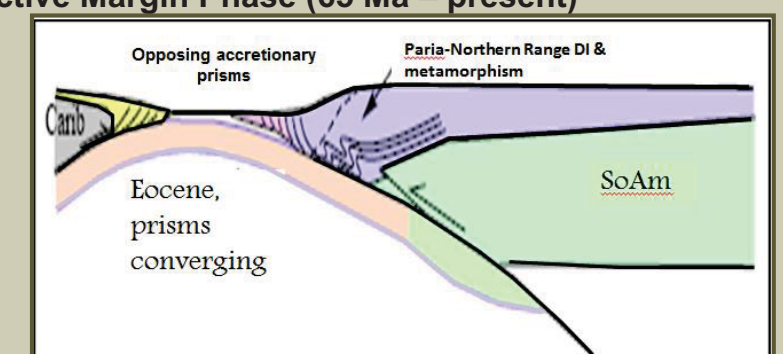


Fig 6 - Early Miocene Oblique Collision (Pindell, 2005)

During the Late Oligocene – Early Miocene, the apparent eastward migration of the Caribbean Plate resulted in oblique collision with the northern margin of the South American Plate, (Fig 6) and as a result, generated a detached fold and thrust belt system within the Greater Trinidad Area.

This collision also resulted in the eastward deflection of the Proto-Orinoco River into the Greater Trinidad Area. The infilling of the foredeep by the Proto-Orinoco resulted in a predominantly down-to-the-East growth fault network.

THE LOS BAJOS FAULT

(Pindell and Kennan, 2006)

- * Formed during SE-directed oblique collision of Late Oligocene – Early Miocene.
- * Associated tear fault and lateral ramp; not traditional dextral strike-slip fault.
- * Oriented such that it mimics the older underlying NW-SE transfer faults of the Early-Middle Jurassic synrift.
- * At Pliocene (Cruse, Forest) time; relative motion of Caribbean Plate transitioning from SE-directed to Eastward Dextral Translation along the northern margin of the highly attenuated South American continental crust.

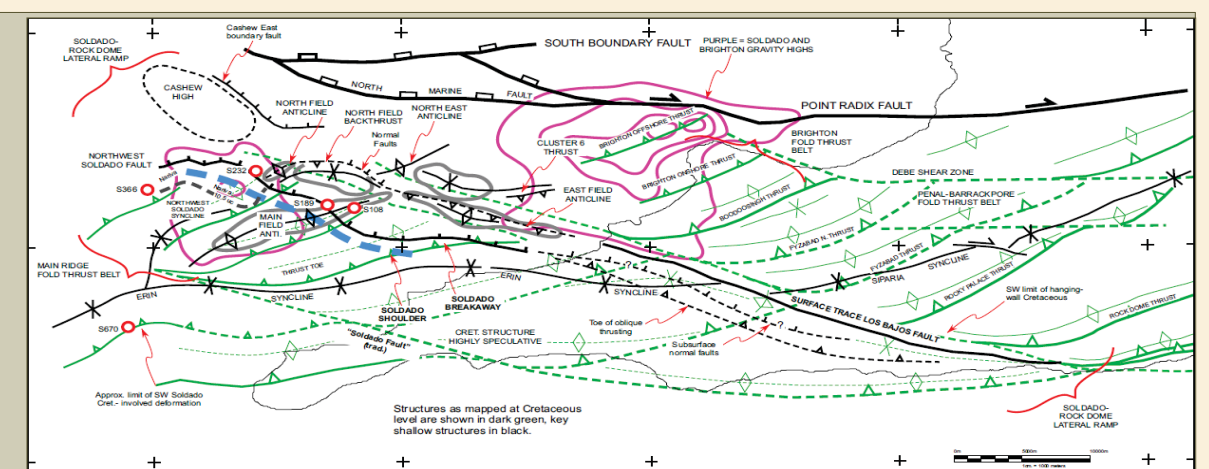


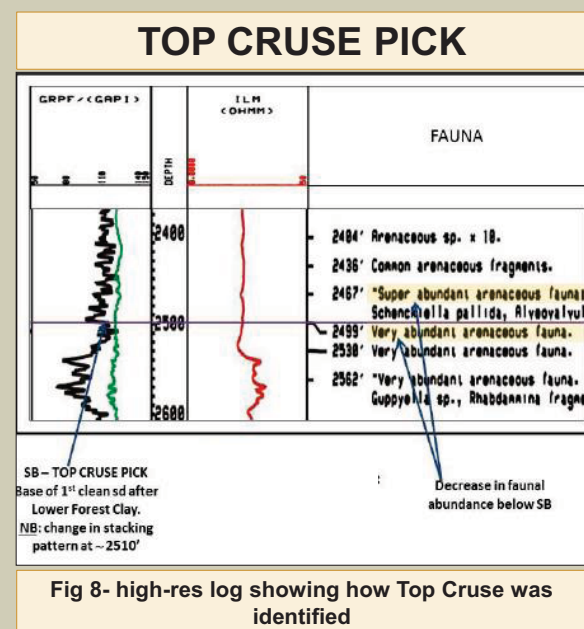
Fig 7 - Main structures associated with the Los Bajos Fault (Pindell & Lorcan, 2006)

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2.1 THE CRUSE FORMATION



- * Analysis was based primarily on structure and isopach maps generated from Upper Cruse sand picks and counts.
- * Surfaces within the Forest and Morne L'Enfer Formations were also mapped to ascertain the lateral continuity of the mapped Cruse sand packages, in cases where the wells did not penetrate Cruse.
- * The Upper Cruse sands are identified primarily by a very specific, arenaceous foraminiferal assemblage; and occur below the Top Cruse surface.
- * The Top Cruse within the HGOR Area is identified on primarily electric logs (GR & ILD) and by a characteristic faunal behaviours. These include:
 - Base of first fining upward, retrogradational sand occurring just below the Lower Forest Clay. The Lower Forest Clay is identified by a specific calcareous faunal assemblage, as it is considered a Transgression Surface (TST2). The Top Cruse is then a Sequence Boundary (SB1).
 - Decreased faunal abundance and diversity (Fig 8).
 - Paleobathymetric shallowing event.

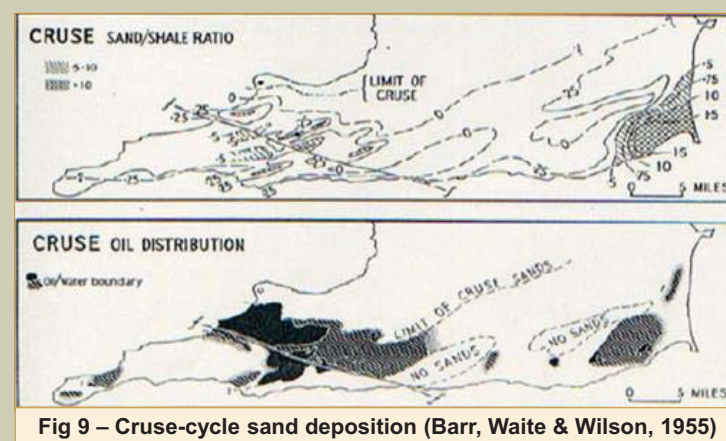


Fig 9 - Cruse-cycle sand deposition (Barr, Waite & Wilson, 1955)

Elongate ENE-WNW trending Upper Cruse sands occur well-developed in the Guayaguayare Area and thin towards the pre-Miocene uplifts (Barr *et al*, 1958). It has been noted that a similar trend is observed south of the Los Bajos (Archie, 2002). This trend is also observed within the HGOR Area, with Upper Cruse sands thinning towards the uplifted Los Bajos Fault.

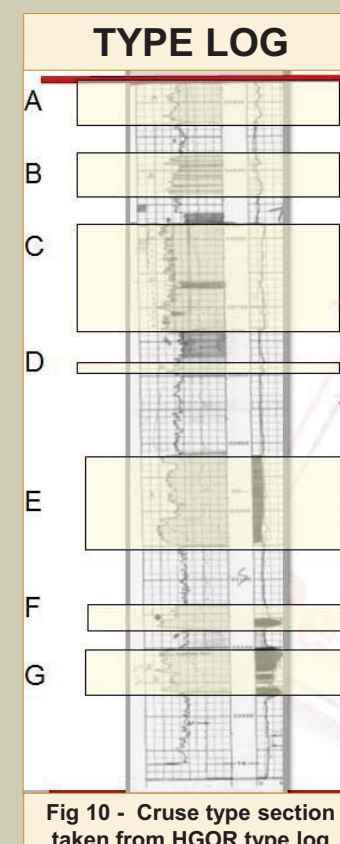


Fig 10 - Cruse type section taken from HGOR type log

2.2 ANALYSIS

STRUCTURAL CROSS-SECTION

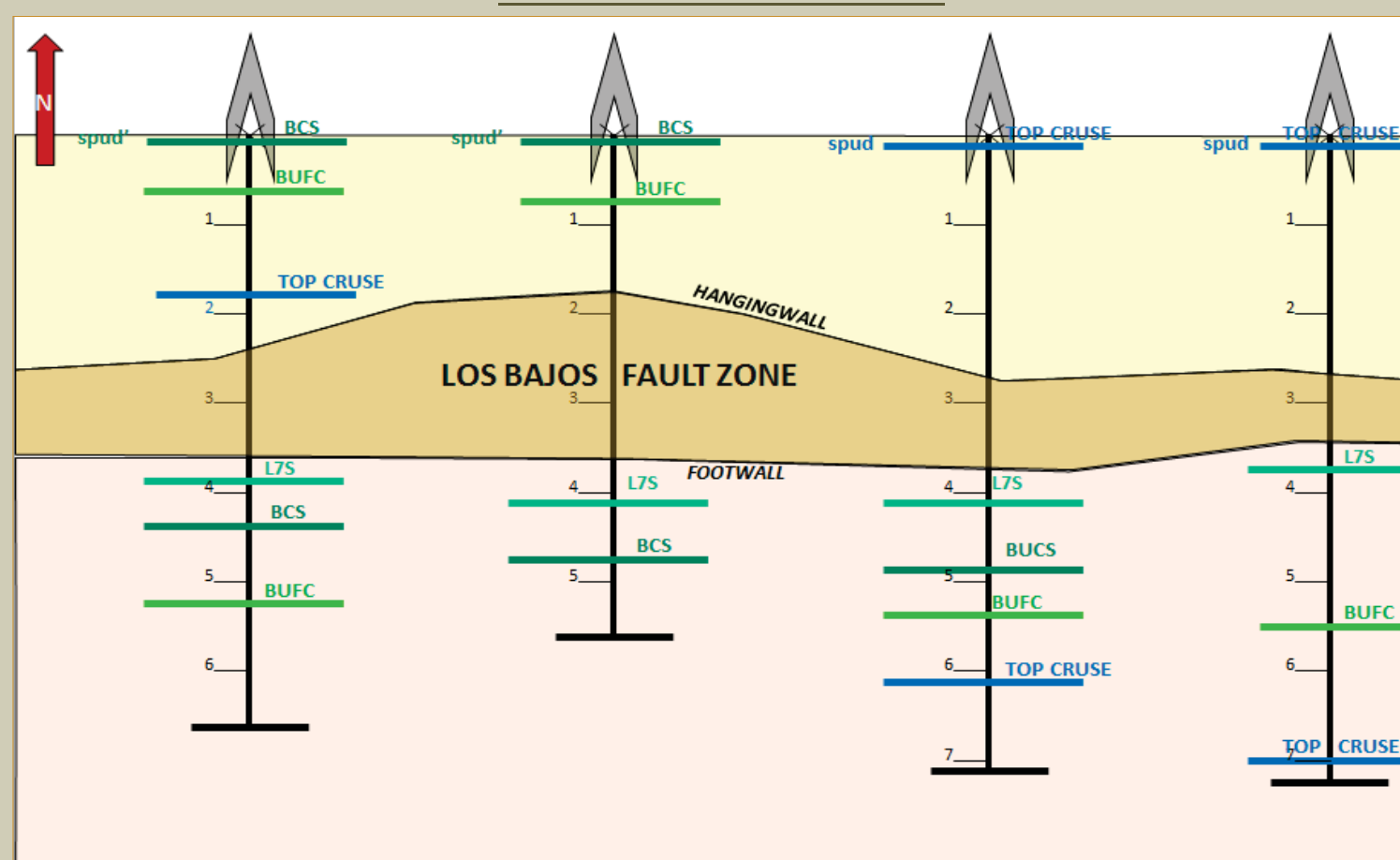


Fig 12 - Structural cross-section across 4 wells along the Los Bajos Fault

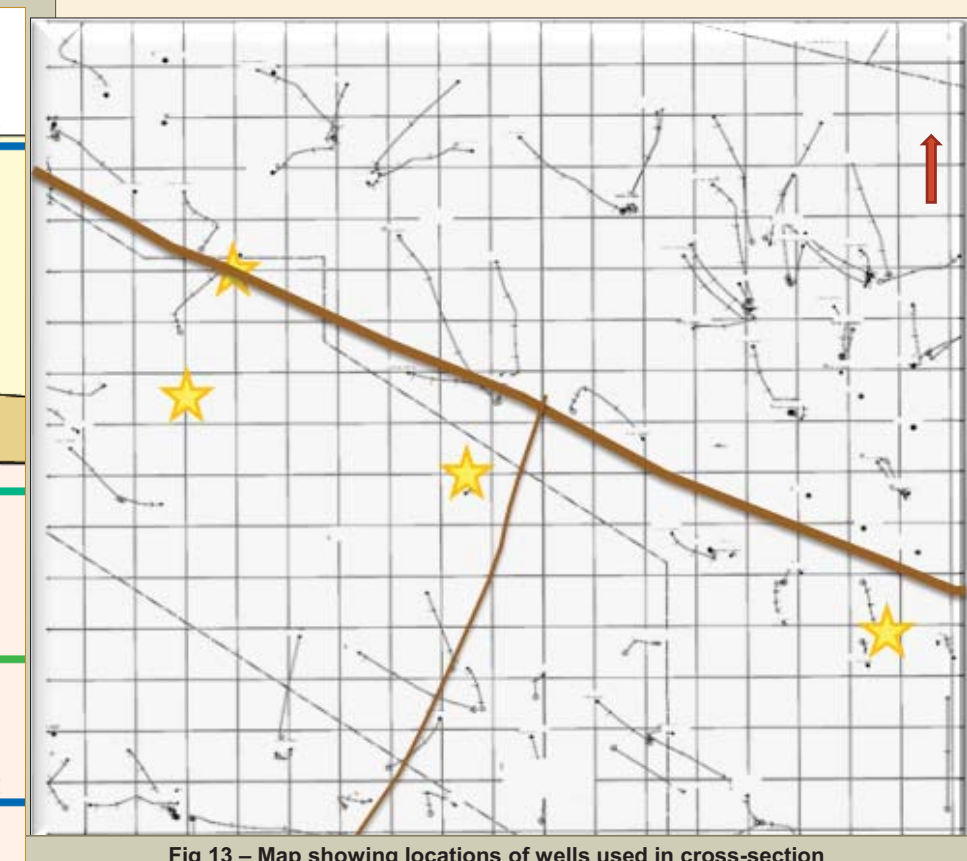
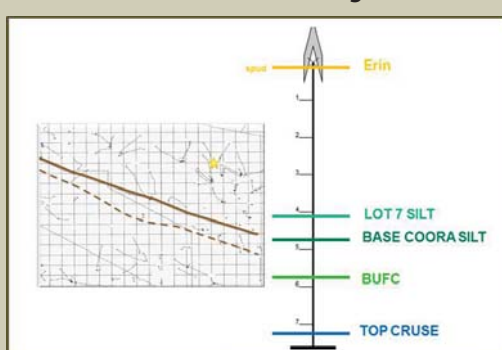


Fig 13 - Map showing locations of wells used in cross-section

DEEPEST WELLS

North Los Bajos



South Los Bajos

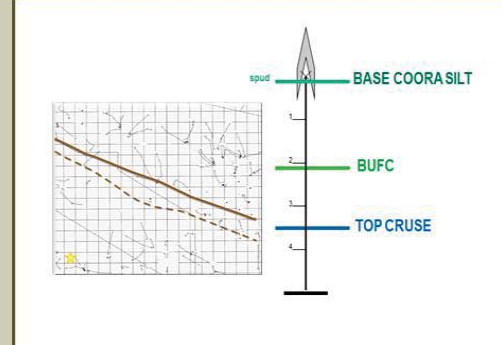


Fig 11 - Deepest wells on either side of Los Bajos Fault

The deepest wells on both sides of the Los Bajos encountered, as expected, stratigraphy in 'normal' chronological sequence. Both wells drilled down to the Upper Cruse sands. North of the Los Bajos, the well encountered Top Cruse at 7000'; while South of the Los Bajos, the greatest depth at which Top Cruse was found is 3500'.

- * A cross section across 4 wells drilled along the Los Bajos revealed the presence of the Los Bajos Fault Zone (Fig 12) - previously thought to be a diapiric mud flow.
- * All wells encountered fault zone and repeat stratigraphy.
- * Fault zone is then indicative of and central to a regime of compressional tectonics; usually associated with these characteristics of reverse/thrust faulting
- * South-dipping Los Bajos Fault is axis of thrust
- * Leads to 2 sets of potential hydrocarbon reservoirs; shallow Miocene/Pliocene reservoirs, and unexplored deep Pliocene reservoirs.

2.3 STRUCTURAL MODEL

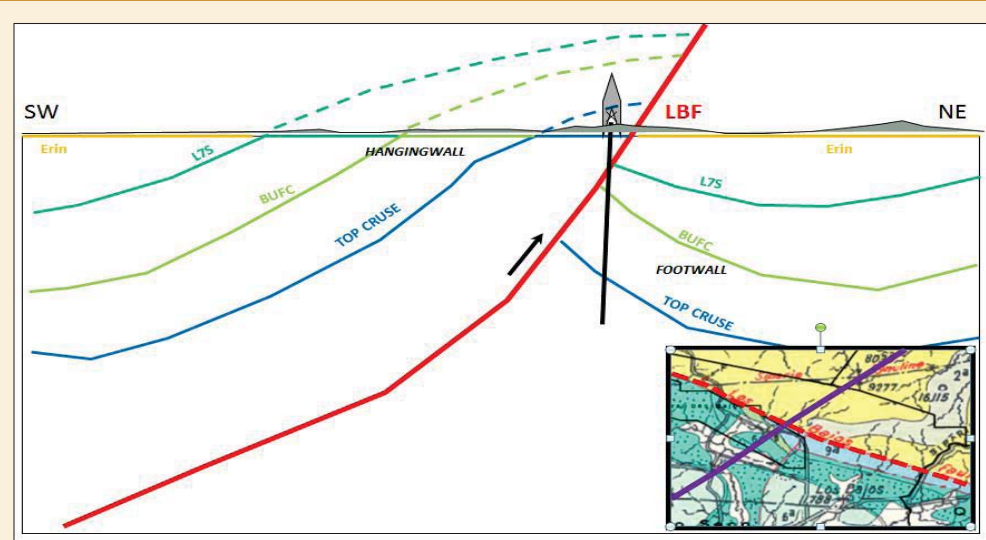


Fig 14 - Proposed structural model on HGOR Area

- * SW-dipping fault is axis of NE-verging thrust.
- * Possible uplift at Cruse time may have offset the deposition of younger stratigraphy-surface geology
- * Expect:
 - ☆ shaleout zones and non-deposition within Pliocene/Pleistocene formations on SW overthrust limb.
 - ☆ normal and growth structure/stratigraphy as a result of sediment loading on the thrust system.
 - ☆ GOR anomalies close to Fault Zone(!), as a result of abnormally-pressured, compartmentalised reservoirs.

- * Seismic interpretations and structural cross-sections support suggested structural model
- * Growth stratigraphy seen

Fig 15b - Structure map on Top Cruse

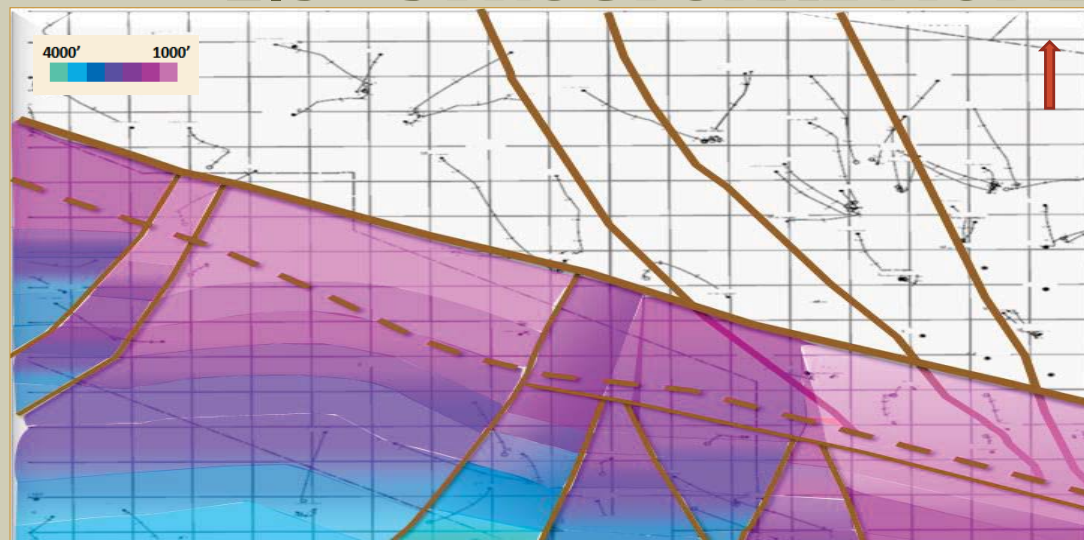


Fig 15a - Structure map on Top Cruse

- * Overthrust limb occurs South of Los Bajos Fault (Fig 15a), 'shallow Cruse' is found here. Underthrust limb occurs North of Los Bajos; 'deeper Cruse' occurs here (Fig 15b).
- * Normal faults occur as splays off the Los Bajos Fault. Prolific reservoirs occur within fault blocks
- * HGOR wells occur close to the Fault zone and are mostly located within the overthrust limb (South)

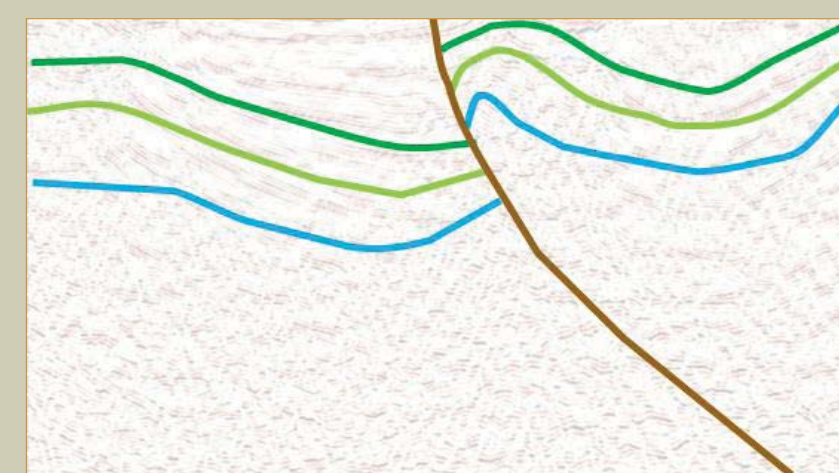
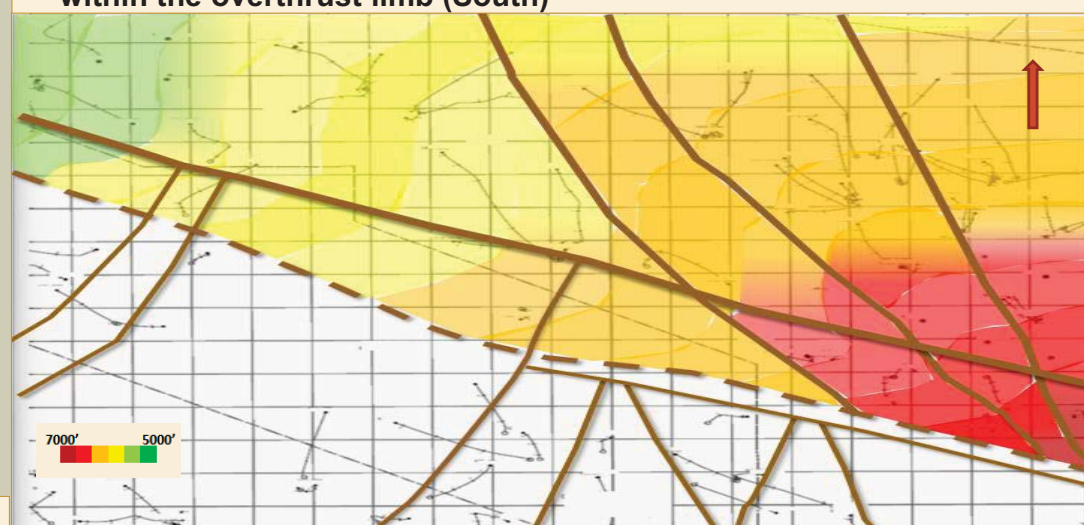


Fig 18 - SW/NE interpreted seismic section

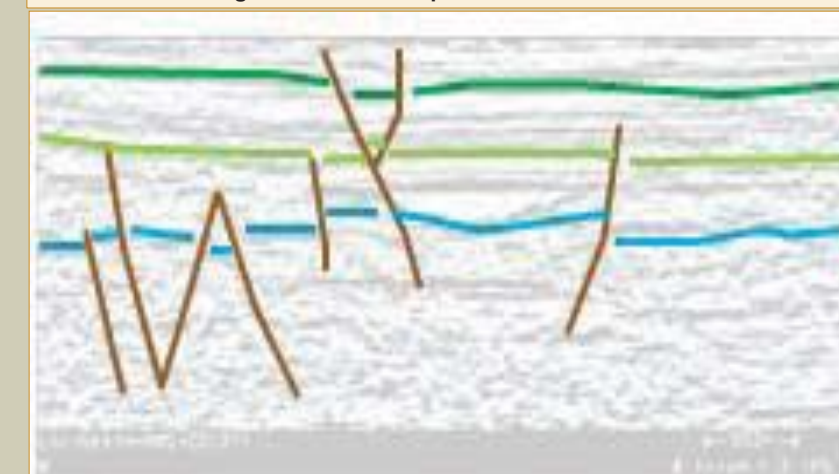


Fig 19 - W/E interpreted seismic section North of Los Bajos Fault

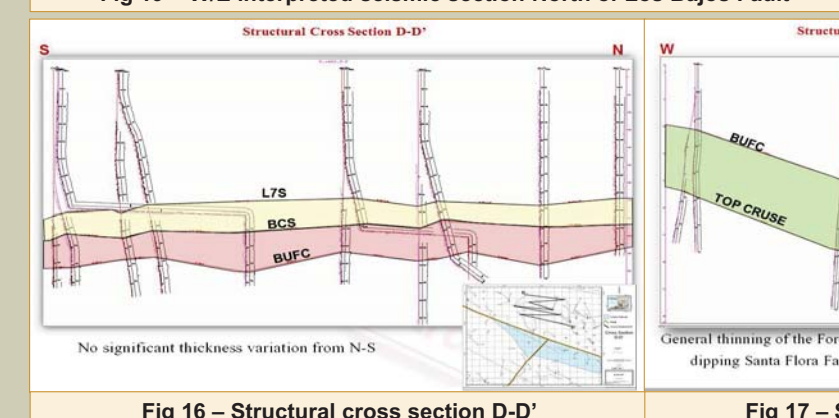


Fig 16 - Structural cross section D-D'

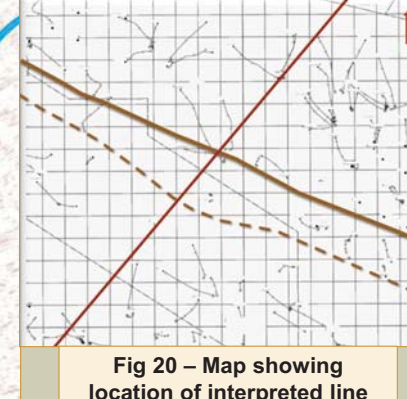


Fig 20 - Map showing location of interpreted line

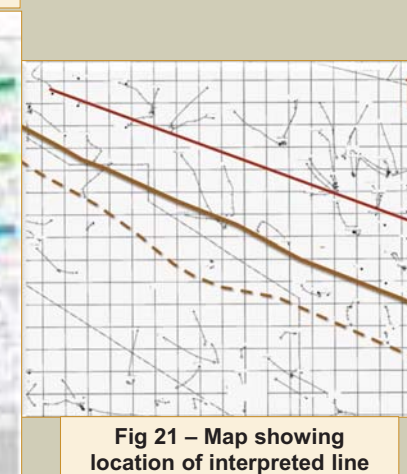


Fig 21 - Map showing location of interpreted line

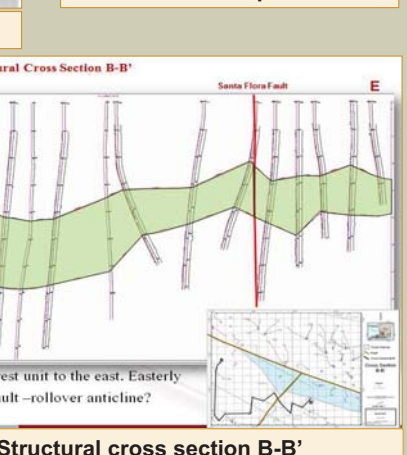


Fig 17 - Structural cross section B-B'



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3.1 STRATIGRAPHIC MODEL

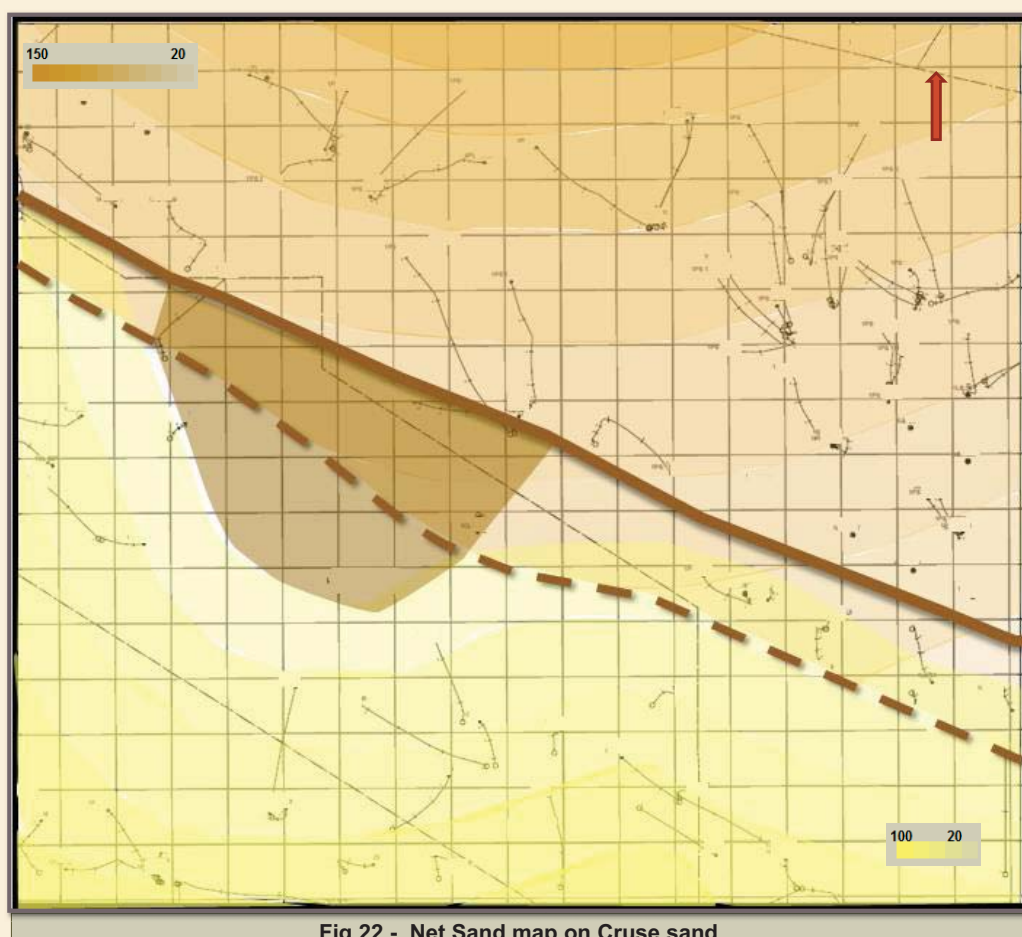


Fig 22 - Net Sand map on Cruse sand

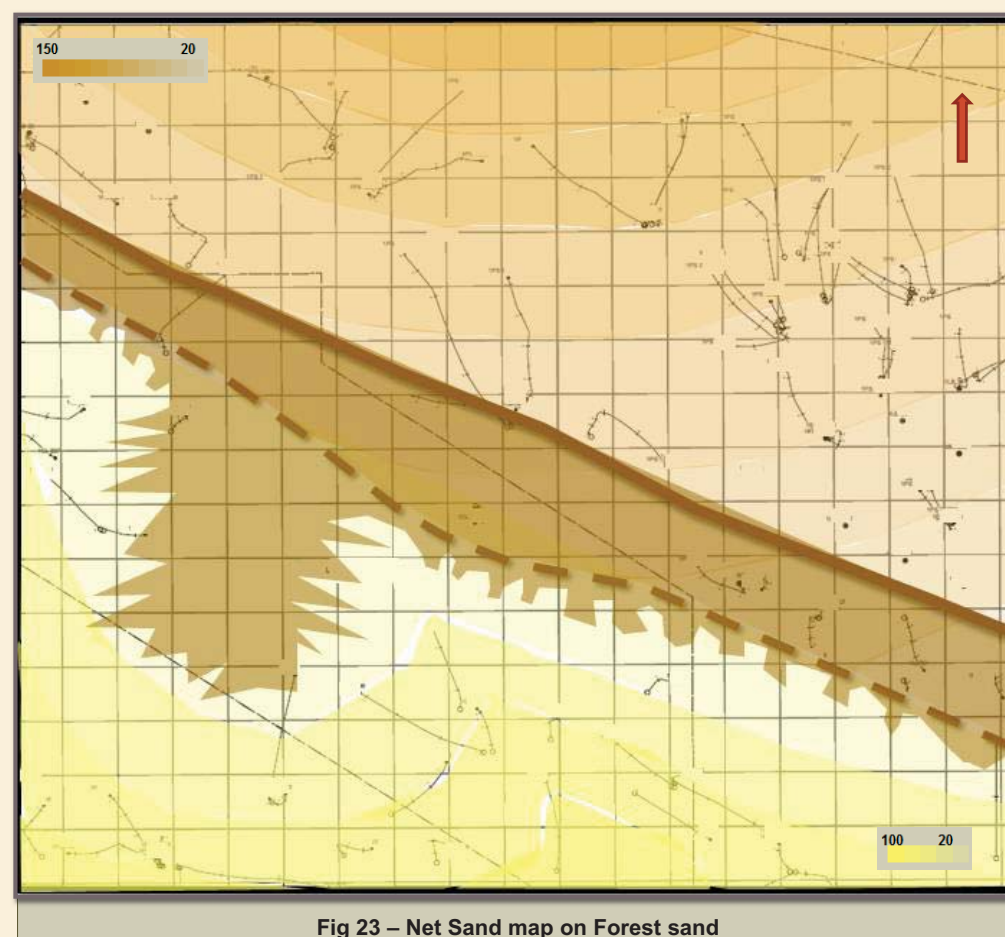


Fig 23 – Net Sand map on Forest sand

- ✧ It is possible that during the Pliocene, during and after deposition of Cruse, the area immediately south of the Los Bajos was slightly uplifted, due to compression/thrusting, discussed in section 2.3.
- ✧ A possible shale out zone to the South intersects with non-deposition closer to the Los Bajos Fault Zone, indicating that the area was uplifted at the time of Cruse and Forest deposition.
- ✧ A zone, highlighted in brown (*Figs 22 & 23*), outlines the 0' contour and may represent the trends outlined above.
- ✧ This uplift continued to grow upward and westward during the Pliocene/Pleistocene, causing deposits to be ponded gradually on the more southern (depressed) side of this uplift. Hence, the highlighted zone is bigger in the Forest sand map.
- ✧ The shape of the uplifted bump also appears dissimilar in both sets of maps; this may be due to folded rock being incorporated into the fault zone, thus distorting the original, smaller shape.
- ✧ Consequently, prospectivity within these formations is very limited in this area, as sands are not typically well-developed and wet in most instances.
- ✧ However, it is likely that deposition continued normally around this uplifted zone, as well-developed, highly resistive sands were encountered around it.
- ✧ The shaleout/non-depositional zone, coupled with the structural setup thereby acts as an effective trapping mechanism for hydrocarbon reservoirs.

3.2 PETROLEUM SYSTEM & CRUDE ANALYSIS

RESERVOIR

- * The log motif of the topmost Upper Cruse sand can be best described as bell-shaped. The fining upward character indicates transgressive sands which, given the setting of the influx of the delta during this time, are likely neritic shelfal (Fig 25).

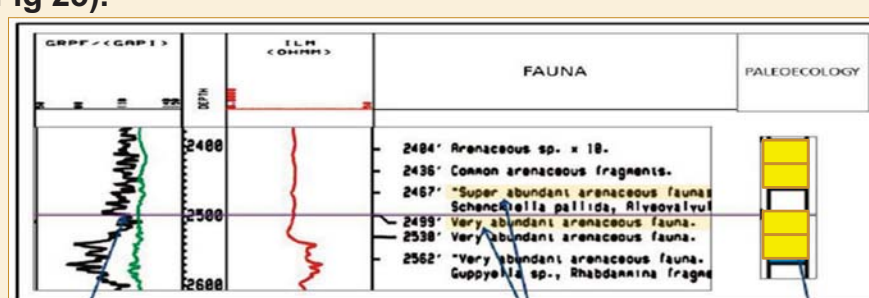


Fig 24 – Semi-high resolution biostratigraphic log within Cruse Interval. Paleogeology plot shows that Cruse sands lie within the Outer Neritic Zone.

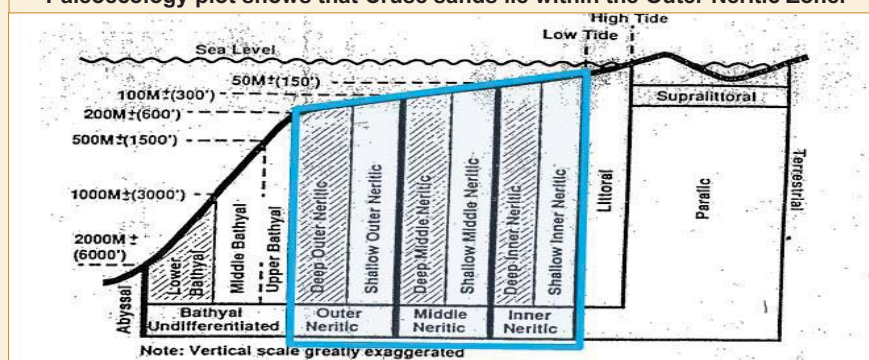


Fig 25 – Distribution of modern bathymetric environments (after Hedgepeth, 1957)

- * Siliciclastic shelf deposits such as barrier islands and sand bars are typically both laterally and vertically extensive. Relict sediments may occur on tidally dominated shelf deposits and include coarse sand and gravel lag deposits. These characteristics are all indicators of good reservoir quality.

SOURCE

The Source Rock in the Southern Basin, South Trinidad is known to be the Upper Cretaceous Naparima Hill Fm (Rodrigues, 1988). See Fig 27.

SEAL

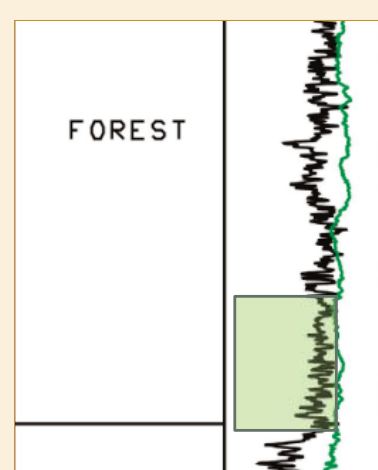


Fig 26 – log showing LFC

- ✦ The Lower Forest Clay (Fig 26) is regarded as an effective seal. Chronostratigraphically, it occurs after the Upper Cruse sand package intervals.
- ✦ A regional clay, the Lower Forest Clay is both laterally and vertically extensive and has good seal potential as demonstrated by occurrence of prolific Cruse hydrocarbon reservoirs.

MIGRATION

Faults detaching on the Upper Cretaceous surface allow for upward migration of hydrocarbons into the younger Miocene and Pliocene reservoirs (Fig 27).

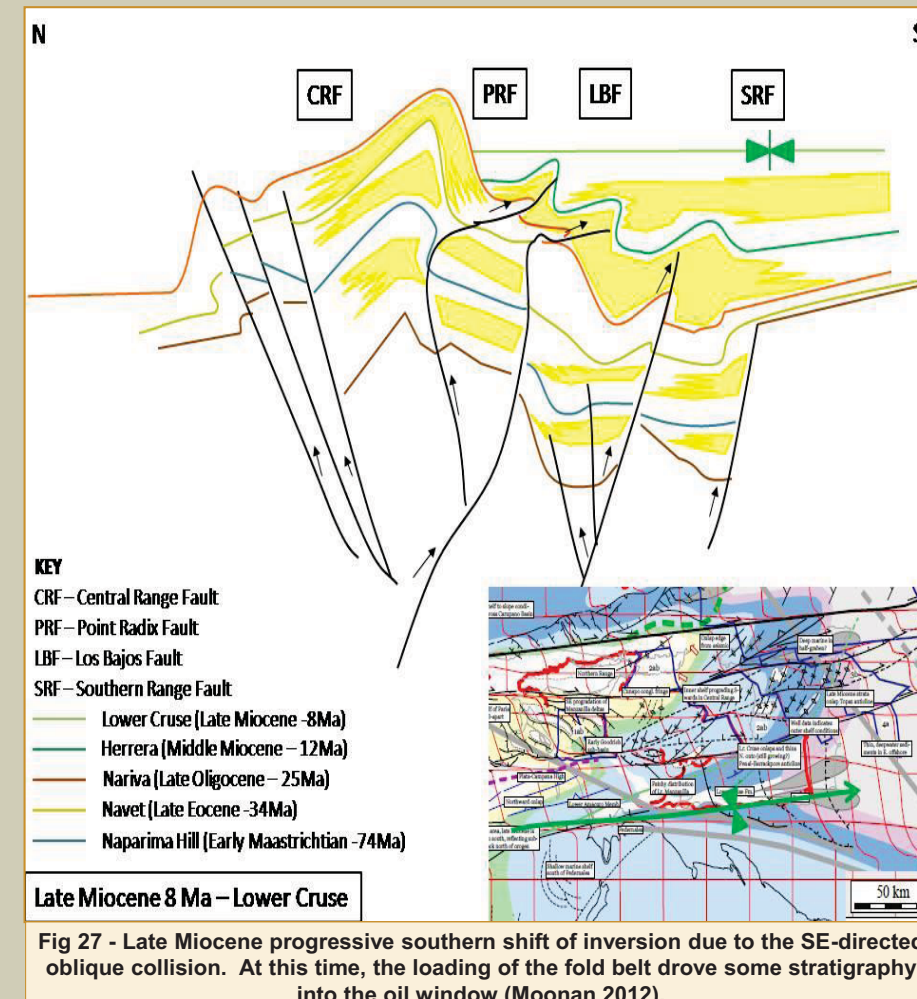


Fig 27 - Late Miocene progressive southern shift of inversion due to the SE-directed oblique collision. At this time, the loading of the fold belt drove some stratigraphy into the oil window (Moonan 2012).

CRUDE ANALYSIS

- * Oils recovered from HGOR Area vary in: composition (naphthene/benzene/toluene content); API; viscosity, etc.
- * Variations may occur within same reservoir sand , as well as by formation.
- * 1943 chemical analysis by Barr, Morton and Richards, within the (nearby) Forest Reserve Field; indicated that such variations/oil mixing can occur from:
 - variations in formation pressures along horizons (as a direct result of continuous production within the reservoir)
 - pressure differences between formations as a result of mixing of oils coupled with upward migration along significant geological structures (faults).
- * Chemical studies within HGOR Area are then recommended to ascertain whether HGOR and variations in crudes are also a result of aforementioned theories vs significant tectonic activity within the area.

3.3 CONCLUSIONS

- * Results indicate that there exists a working petroleum system within the Cruse reservoirs, both North and South of the Los Bajos surface trace and exploitation/further drilling is viable.
- * Study was able to identify zone of shale out/non-deposition to further aid in delimiting potential drilling locations. Los Bajos surface trace is not true indication of subsurface thrusting.
- * Crude analysis shows that HGOR is most likely a result of heightened compressional tectonics, coupled with evaporative fractionation phenomenon and/or mixing of oils within reservoirs. Chemical analysis recommended.
- * HGOR is most likely to occur very close to the fault zone; within both overthrust and underthrust limbs of Morne L'Enfer, Forest and Cruse.
- * Reservoir characterization and simulation is recommended for classification of optimal production/recovery techniques.
- * Further in-depth geophysical studies are also recommended.

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- * Special thanks to Ms. Carol Telemaque, Senior Manager ExD; Mr. Curtis Archie, Manager Exploration and Geophysics; Mr. Chris Lakhan, Head Biostratigrapher and Petrotrin's Cartography Department for their support and guidance in completing this poster.

3.5 REFERENCES

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