Petroleum Prospects of the Middle Tertiary Reservoirs in the Southwest Peninsula of Trinidad*

Krishna Persad[1] and Neil Ritson[2]

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[1]Beach Oilfield Limited (krishnamppersad@gmail.com)
[2]Leni Gas and Oil PLC

Abstract

Geo-tectonically, the Southwest Peninsula (SWP) of Trinidad lies within the Southern Basin which is a piggy-back basin filled with Pliocene to Pleistocene sediments. The Southern Basin (Figure 2) extends eastwards onshore southern Trinidad and westwards into the southern Gulf of Paria. Throughout its extent it is underlain by the Naparima Nariva Fold and Thrust Belt (FTB) which extends further to the south and east onshore (to the Southern Range Anticline) and also offshore the East Coast (to the north and east).

In the onshore, while the younger Plio-Pleistocene reservoirs have yielded the bulk of the oil produced to date (over 1.5 billion barrels), turbidite sand members of the Cipero Formation (Karamat, Herrera and Retrench) are also significant producers of oil and more recently gas. Some 200 million barrels of oil have been produced to date from these reservoirs onshore, current production being over 3,000 BPD of liquids and 70 MMCFGD.

With the exception of the SWP, the Southern Basin has been at least moderately explored. Deeper exploration, to the Middle Tertiary has however been incomplete (and restricted to areas east of the Los Bajos Fault) because of the complexity of the

overthrusting within the FTB and the difficulty of identifying the structures within the FTB. Within the SWP itself, exploration of any kind has been sparse, with only about thirty wells having been drilled to date. Even more significant, there has been only one single penetration into Upper Miocene Lengua age reservoirs and no well has yet penetrated the Middle Miocene Cipero age reservoirs which are known to exist and to be hydrocarbon bearing further to the west in the southern Gulf of Paria and in Eastern Venezuela.

Geochemical work conducted on produced oils from within and areas adjacent to the SWP and from oils extracted from oil saturated Herrera sands ejected from the mud volcanoes in the area, have confirmed the presence of a viable petroleum system with Herrera sands as the reservoir and Upper Cretaceous rocks as the source. In addition, data from wells and seismic, including a relatively new 3D seismic data set, have identified the presence a highly prospective trend within the SWP in general and one large structure in the Cedros area onshore.

This article will briefly discuss the geo-tectonic history and the petroleum system we have identified. It will then outline the play and prospect we have identified. Finally we will talk briefly about two tools that we plan to use to upgrade our knowledge of the known prospect, and to identify other prospects within the play trend, namely full tensor airborne gravity (FTG) and surface geochemistry.

Geologic and Tectonic History

We have found that a seven-stage evolutionary model for the Trinidad area best fits all of the data, as follows (Figure 1):

1) Pre-Rift, Syn-Rift and Drift (Late Jurassic-Mid Cretaceous)

A) Pre-Rift Phase
This phase comprises pull apart and sea floor spreading, accompanied by thick suites of sediments, in response to crustal attenuation and cooling. Prior to that North America was welded to South America, with the Yucatan Block in between. The proto-Caribbean Seaway had previously opened with the probable initial rotation of the Yucatan Block away from South America about a pole around the northwestern tip of South America.

B) Syn-Rift Phase

As the Yucatan Block pulled further away, extensional tectonics similar to that occurring in the typical syn-rift stage predominated, and evaporite deposition occurred in the proto-Caroni Basin, and extended westward into eastern Venezuela, into an area known as the Espino Graben. This graben is now recognized to be as old as Cambrian in age, and to extend as far west as the Colombian border. Within the
graben Upper Jurassic basaltic volcanics dated at 162 million years have been found, together with red-beds. The extensive evaporites could be the mobile rocks on which the older thrust sheets of the fold-thrust belt slid, at least in the Trinidad area. Northwest of the graben the proto-Araya Northern Range (ANR) Terrane was left behind as the Yucatan block moved away. The carbonate platform sitting on the leading edge of the proto-Araya-Northern Range Terrane moved southeast in later collisions associated with the westward translation of South America relative to the Caribbean Plate.

C) Drift Phase
Continuing separation between the Americas occurred within the proto-Caribbean seaway with the initiation of a southwest-trending spreading centre between South America and Yucatan. Thick turbidites most likely represent lowstand basin floor and slope fans formed during falling sea level or lowstands of Lower Cretaceous times.

2) Passive Margin (Mid-Late Cretaceous)

Northern South America remained a passive margin, with a stable platform and uninterrupted sedimentation into the Paleocene in the west and Eocene in the east. The anoxic shales of the Gautier and Naparima Hill formations of Upper Cretaceous age were formed during one of the highest stands of sea levels in Earth's history, seemingly accompanied by significant upwelling.

3) North-South Compression (Late Cretaceous-Eocene)

As the proto-Caribbean continued drifting to the north, a spreading center was seemingly initiated. By latest Cretaceous, compression-induced subduction seems to have started on both the northern and southern flanks of the interrupting the passive margin.

4) Return to Passive Margin (Eocene-Oligocene)

Oblique convergence between the Caribbean Plate and northern South America started in the west in the Paleocene; it did not reach the Trinidad area until Late Oligocene. During this period (i.e. prior to Late Oligocene) the Trinidad area seems to have been dominated by a return to passive margin conditions, with main sedimentary input still coming from the Guyana Shield area to the south and southwest.

5) Sequential Oblique Collision (Late Oligocene-Mid Miocene)

The effects of the oblique collision in the Trinidad area were:

A) Overthrusting of the metamorphic Northern Range Terrane onto the proto-Caroni Basin.

B) Development of a series of highly asymmetric anticlines formed within the overthrust east-northeast to west-southwest trending Oligo-Miocene detached fold-thrust belt.

C) Downward loading of the crust south-southeast of the active old thrust belt.

D) The development of a thick sequence of turbiditic sediments in the fore-deep basin, trending east-northeast to west-southwest, just in front of the leading edge of the fold-thrust belt.

6) Wrench Phase (Late Miocene-Recent)

In Late Miocene times (around 13 ma) the Gulf of Paria pull-apart Basin was formed as the right lateral movement of the El Pilar in eastern Venezuela stepped over via an oblique wrench on the eastern coast of Venezuela to the Warm Springs Fault and to the Central Range Fault.

7) Continental Embankment (Deltaic Phase) (Pliocene-Present)

When the Caribbean Plate reached the eastern end of northern South America, the main part of the delta pushed eastward into the open Atlantic. Eastward progradation resulted in the migration of the deltaic depocenters, of which four are recognized, two in the Pliocene, and two in the Pleistocene.

Relevant Tectonic Areas

The Naparima Nariva Fold-Thrust Belt (FTB) (Figure 3) is a westward continuation of the Barbados Accretionary Prism (called the Carapita-Nariva Accretionary Wedge by Flinch et al (1999) who also call the Barbados Accretionary Prism the Barbados Accretionary Wedge) (Figure 5). It comprises a series of fore-deep basins younging to the south-southeast and affected by a number of detached overthrusts which range in age from Lower Miocene in the north-northwest to Lower Pliocene in south-southeast. Those thrusts in the south-southeast are blind thrusts, underlying the thick sediments of the Columbus Basin.

Each thrust changes character to the west and becomes an oblique strike-slip fault, probably lateral ramps along which the shortening has taken place. A number of medium to large oil fields have been found within the FTB and the area is largely unexplored or under-explored. Most of the structures in eastern south Trinidad are yet to be tested and there has been no penetration of the Herrera Formation onshore south Trinidad west of the Los Bajos Fault.

The Piggy-back Southern Basin which overlies part of the FTB is filled with deltaic to fluvial sediments of Upper Miocene to Pleistocene age, sourced from a secondary lobe of the Orinoco Delta. Along the basin margins, lines of mud volcanoes are found. They coincide with the overthrusts and are mobilized Miocene shales and newly generated methane from Cretaceous source rocks.

The Central Range Fault Zone was reactivated in the Upper Miocene as a series of transpressive faults, trending northeast to southwest, which resulted in the renewed uplift of the core of the Central Range. In the eastern offshore a number of other asymmetric piggy-back basins, associated with the FTB, trending northeast to southwest can be found, namely the Manzanilla Sub-basin and the Galeota Sub-basin. They are all filled with mainly Mio-Pliocene and younger sediments. To the southwest, the Fold-Thrust Belt extends into the Southwest Peninsula and further southwest into the Gulf of Paria and then into eastern Venezuela. We believe that significant potential remains for new discoveries in southern Trinidad including in the Southwest Peninsula.

Geochemistry

The vast majority of all oils are sourced by the Upper Cretaceous Naparima Hill and Gautier formations. This source is mostly mature. To the north the source is mostly pure marine, while in the south and east it contains terrigenous input. The terrigenous component has partly accounted for the high incidence of gas/condensate fields in the Columbus Basin, but these fields are also fractionated. The discovery of black oil below the gas/condensate zones has helped to confirm this.

Many oils are biodegraded and others were also fractionated, yielding shallow gas and gas/condensate accumulations, the latter known as fractionated condensates and leaving behind oils known as residual oils (Figure 6 and Figure 7). The fractionated condensates are generally enriched in aromatics and of much higher API gravity, while the residual oils are waxier and heavier. Often the biodegraded oils were mixed with altered migrating condensates. Finally all oils and condensates were expelled at normal temperatures and no over-mature condensates have been identified to date.

The Mid-Tertiary Gautier/Naparima Hill-Cipero (!) Petroleum System is known to exist onshore southern Trinidad, south of the Central Range, and westward into the Gulf of Paria. The reservoirs extend in three major fairways all trending northeast-southwest to ENE-WSW. They are from north to south, the Nariva fairway, the Retrench Fairway and the Herrera Fairway. The latter can be sub-divided into the Cipero and Karamat Herrera fairways. Potential extensions of these trends have been postulated by Persad (2011) who has suggested that they could contain significant accumulations of hydrocarbons. For example he has postulated a westward extension to the Herrera Trend west of the Los Bajos Fault into the Southwest Peninsula onshore and then offshore into the western Gulf of Paria.

In the SWP, shallow oils have been found in the Bonasse and Icacos areas. These oils were analysed and interpreted as fractionated oils, suggesting deeper potential. There are two other pieces of evidence supporting this: The Galpha Pt. and Islote Pt. Mud volcanoes have ejected blocks of Herrera oil sand geochemically analysed as light residual oil. The recently drilled FRM 1 well and the older ACD 4 well both found light oils and/or condensates in Lower Cruse-Lengua reservoirs.

Large oilfields have been found in the Pliocene and younger section in the central part of the Southern Basin (Figure 1 and Figure 8). Over 1.2 billion barrels have been produced to date in the onshore portion alone. In the eastern part of the basin, however, only two oilfields have been found in the Pliocene and younger section. In the western onshore part of the basin there is also a dearth of petroleum accumulations, with only the Icacos and Bonasse fields found to date.

If we look at the older sediments, we see that all the hydrocarbon discoveries (which are in the Herrera Sand Member of the Cipero Formation), are in the eastern part of the basin and there are no commercial discoveries in the Fold and Thrust Belt sediments in the western part of the Basin.

On geochemical considerations we expect to find evaporatively fractionated light oil and condensate in Upper Miocene and younger reservoirs and residual oils in Herrera reservoirs and we predict that the shallow oils may be biodegraded and mixed with condensate. The intermediate-depth light oil/condensates in Lengua/Lower Cruse sands will be around 50 degrees API, i.e. not biodegraded. The residual oils will be in the Herrera sands and 25-28 API.

Structural Considerations

In the Southwest Peninsula wells date back to 1911. Exploration includes wells, and more recently 3D seismic. The early wells found some oil but the fields were small. The later wells targeted deep Herrera sands but none reached their objective, so to this date no large accumulations have been found.

On the basis of the 3D seismic a number of structural highs have been identified in the SWP area along the trend of the Southern Range Anticline (Figure 4) at the Lower Cruse-Lengua and Herrera levels. In the Cedros Estate Area a large (4800 plus acre) deep structure has been identified on seismic with oil potential in Middle Cruse, Lower Cruse, Lengua and Herrera sands (Figure 9). The structure is separated into two parts by a north-south wrench system which terminates against the Southern Range Anticline. We estimate the Cedros Estate structure alone to have a potential for 500 million barrels of recoverable oil, and the trend over 2 billion barrels in the deep horizons.

Two Tools That Will Help Define Leads and Prospects

Air Full Tensor Gravity (FTG)

Air-FTG® is a system that provides high resolution airborne full tensor gravity gradient data. The FTG acquisition system measures minute changes (gradients) of the Earth's gravity caused by density differences in the local geology. The FTG acquisition system gives significantly higher resolution than conventional airborne gravity surveys FTG (full tensor gradiometer) provides the high resolution that is necessary to properly image shallow structures (Figure 10). It is a cost-effective alternative to further seismic acquisition Leni Gas and Oil will be conducting an AIRFTG Survey over all of southern Trinidad including the SWP. We intend to use the results to help refine data already in house

Surface Geochemistry

Micro-seeps of hydrocarbons are present above oil and gas accumulations, having migrated more or less vertically out of the accumulations. They can be detected by collecting surface samples and doing geochemical analyses. Surface geochemistry has been used successfully in many parts of the world (Figure 11). Surface geochemical surveys are useful when seismic is poor, as in the Southwest Peninsula of Trinidad (Figure 12).

We intend to collect around 400 geochemical samples in acreage held by us in the SWP and have them analysed to further fine-tune our interpretations. The objectives of the survey are to determine:

- The magnitude and extent of micro-seepages in the area.
- The composition of the hydrocarbons...oil versus gas.
- The likelihood of hydrocarbon charge in already identified leads and prospects.

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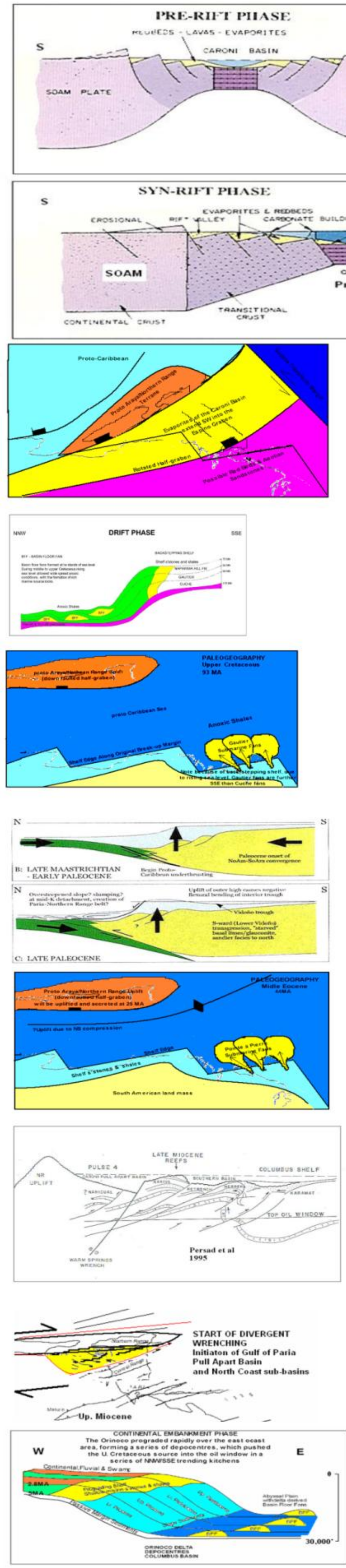

Figure 1. Schematic cross sections and map views of the tectonic and paleogeographic history of the Trinidad area.

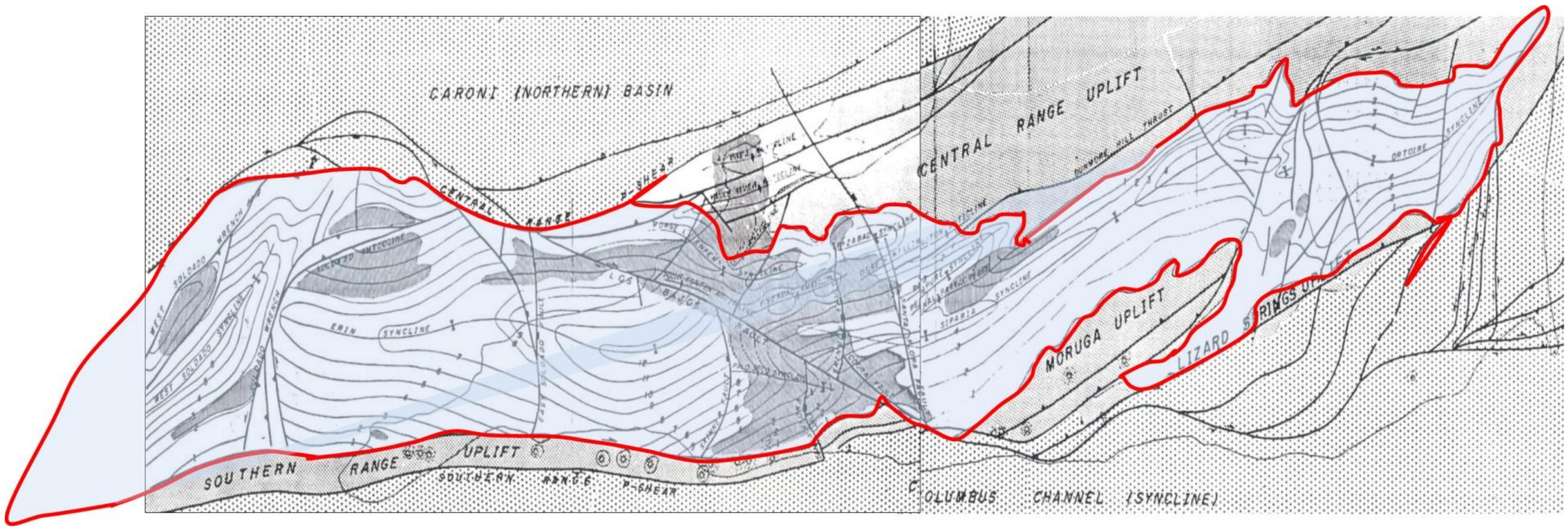

Figure 2. Geographic extent of the Southern Basin, from Persad (2011).

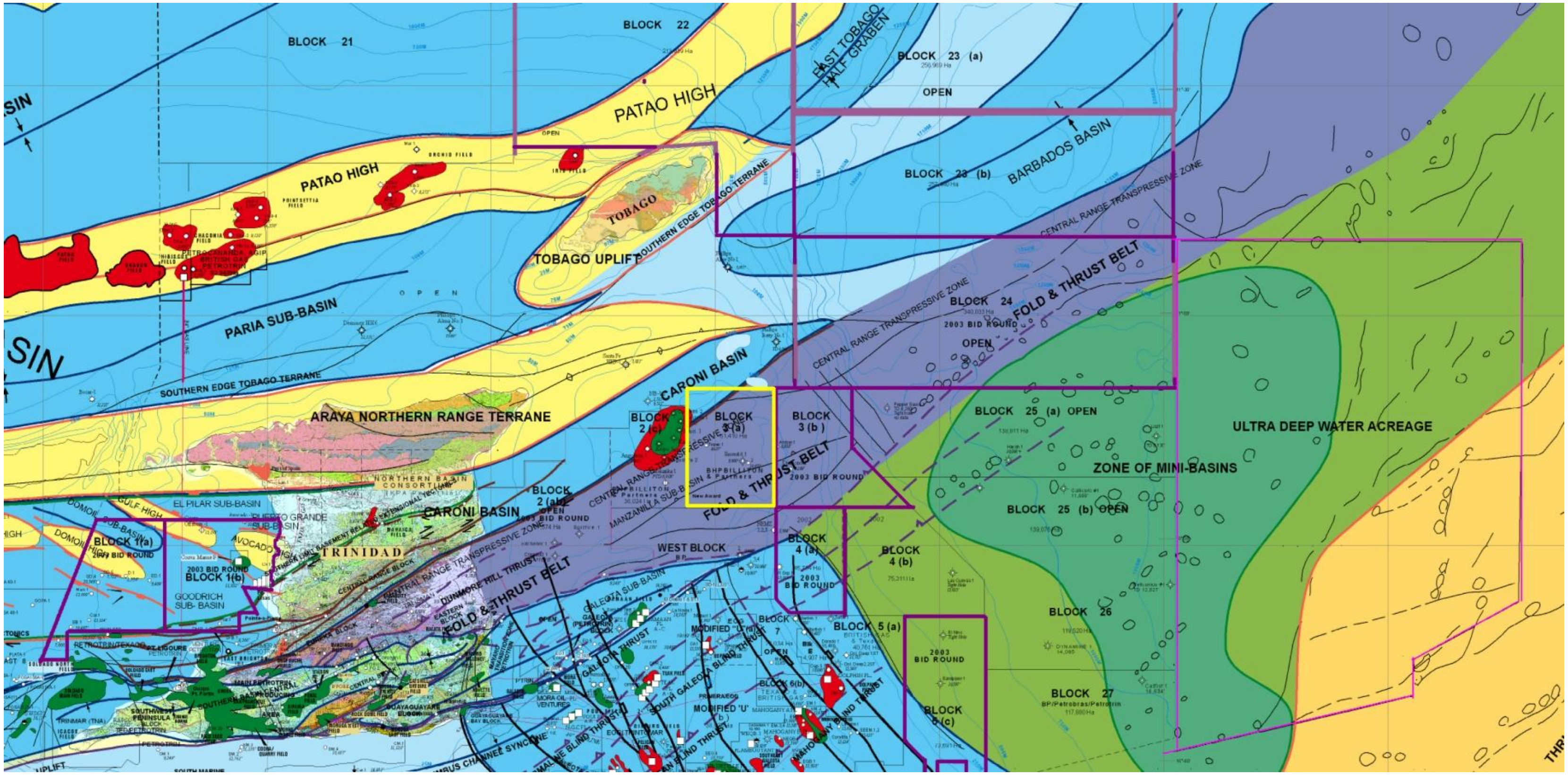

Figure 3. Geographic extent of the Naparima Nariva Fold-Thrust Belt in Trinidad and Tobago, from Persad (2011).

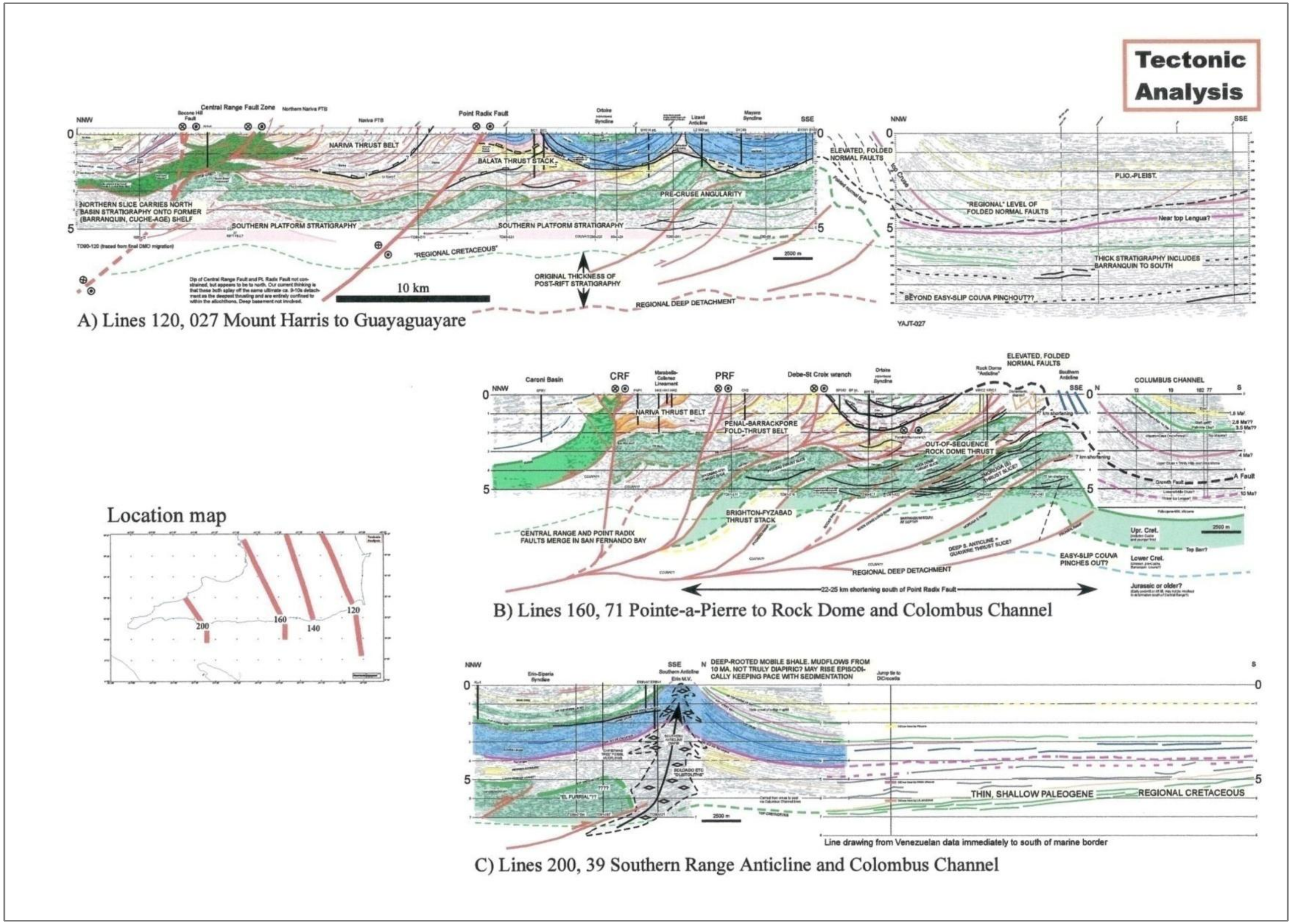

Figure 4. Onshore seismic sections of structural styles in south Trinidad, from Kennan and Pindell (2007).

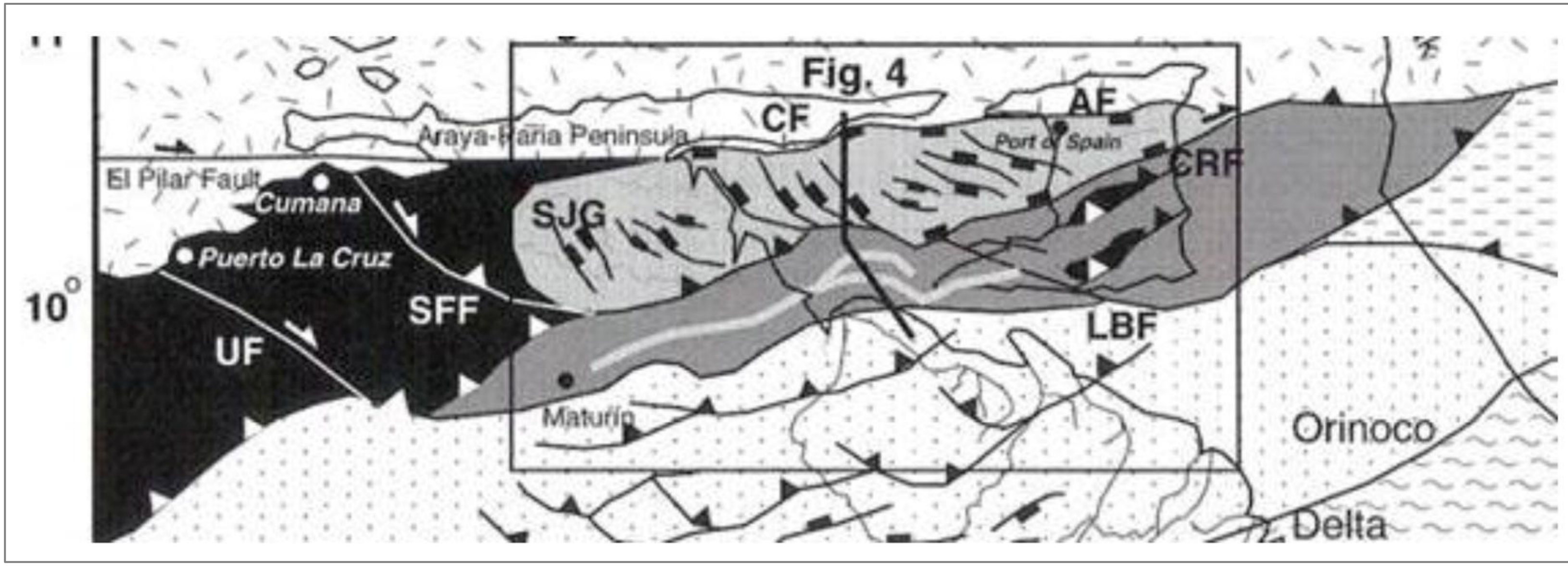

Figure 5. Extension of the Fold-Thrust Belt into eastern Venezuela, from Flinch et al. (1999).

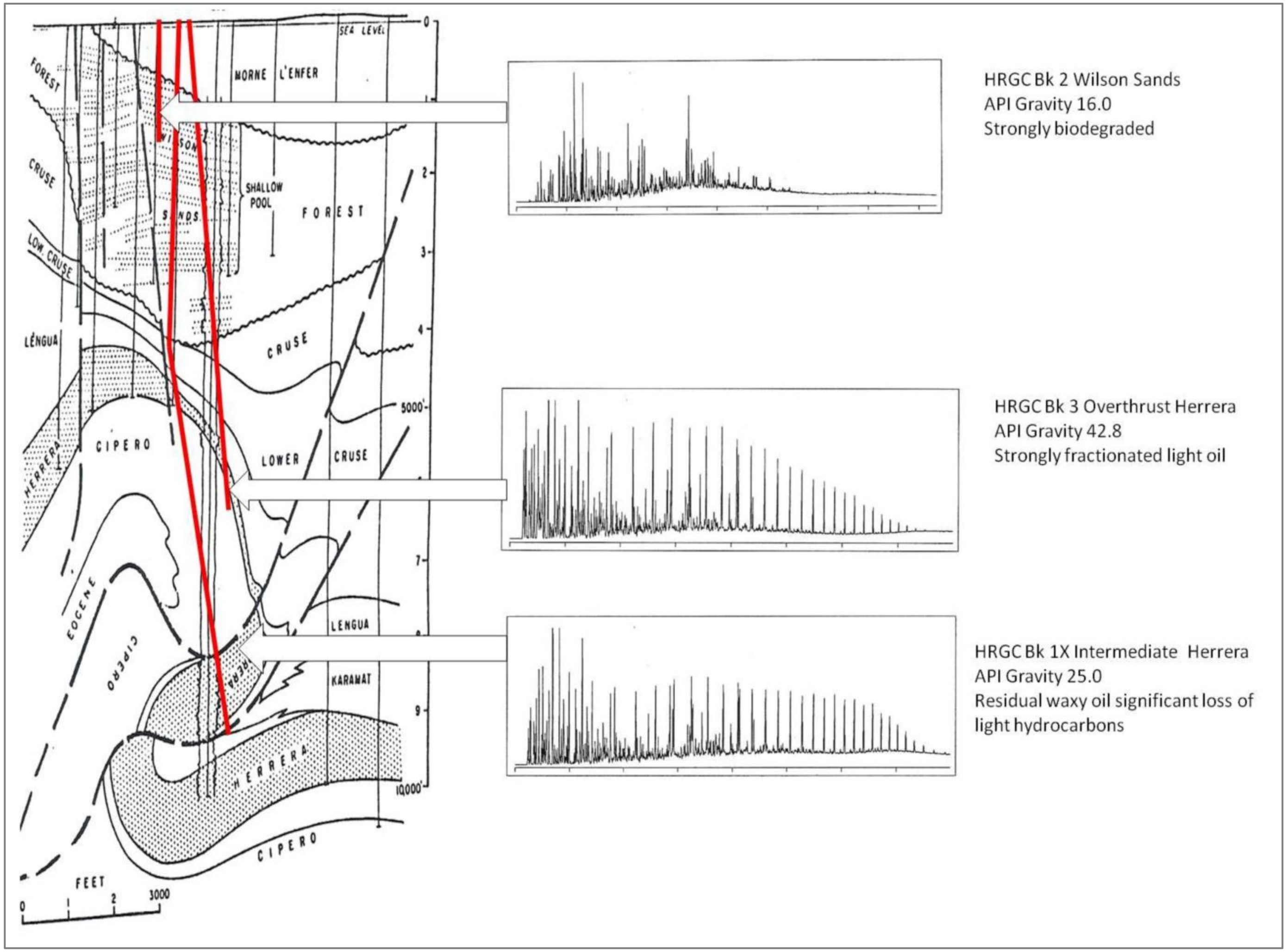

Figure 6. Typical cross section of Barrackpore Field showing structural relationships of Wilson and Herrera formations and relative locations of KPAL's Bk 1X, Bk2 and Bk3 wells. The shallow oils in the Penal-Barrackpore Field are altered by evaporative fractionation, the residual oils being left behind in deeper Herrera reservoirs.

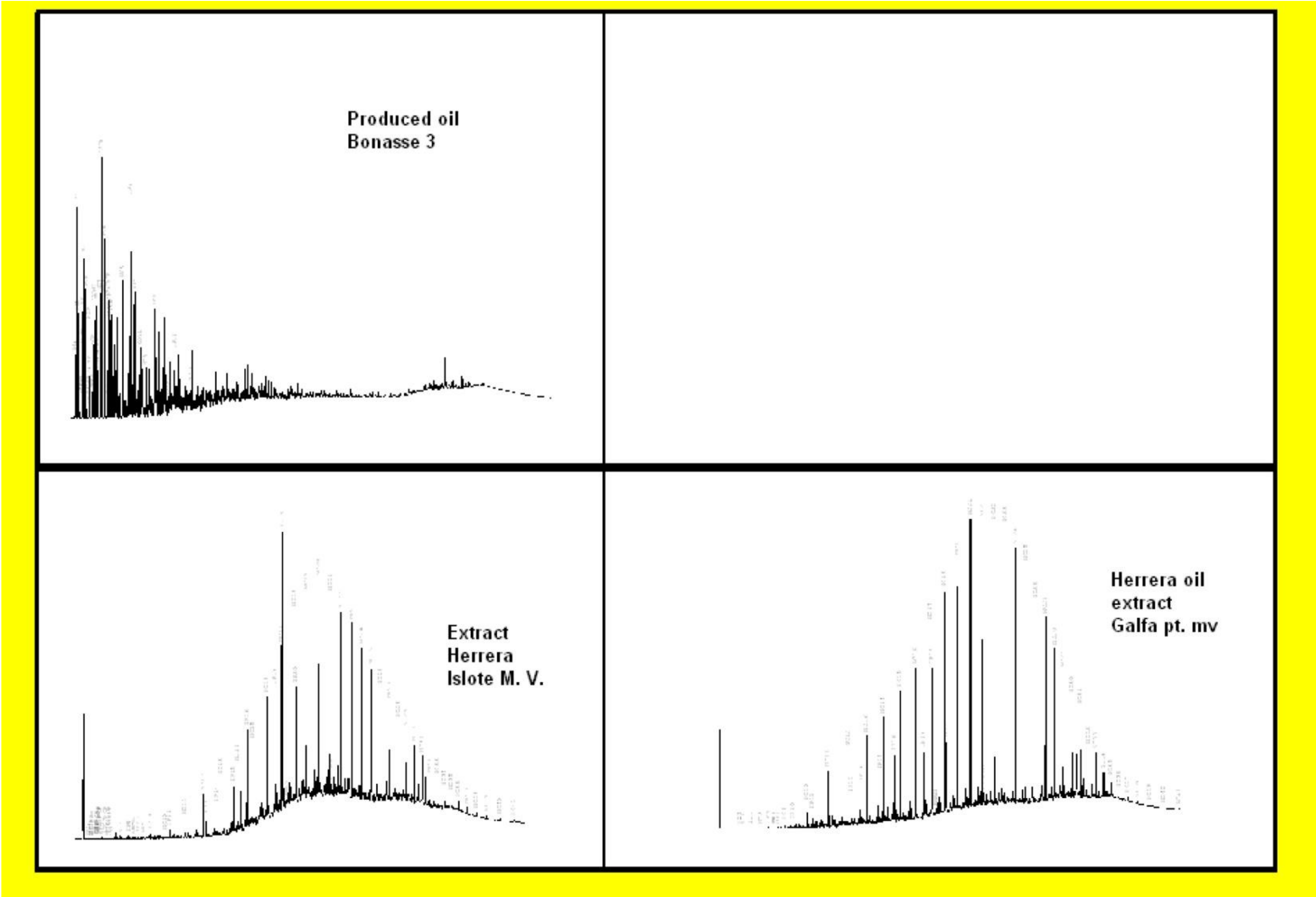

Figure 7. Geochemistry of HRGC's oils in the Southwest Peninsula. All oils from Cruse, produced oils, seeps and oil extracts, are biodegraded but mixed with condensates, implying deeper residual oil, i.e. Herrera. Both extracts from Herrera blocks ejected from mud volcanoes are in fact residual oils.

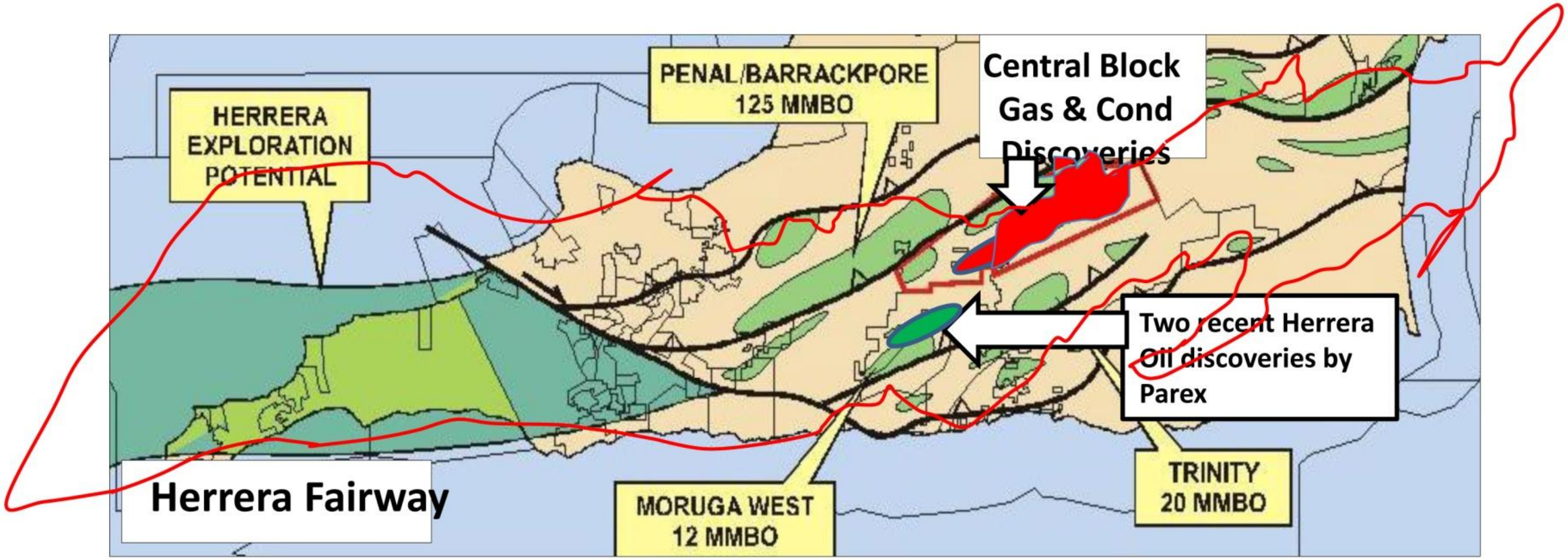

Figure 8. Commercial discoveries in the Fold and Thrust Belt sediments in the western part of the Southern Basin.

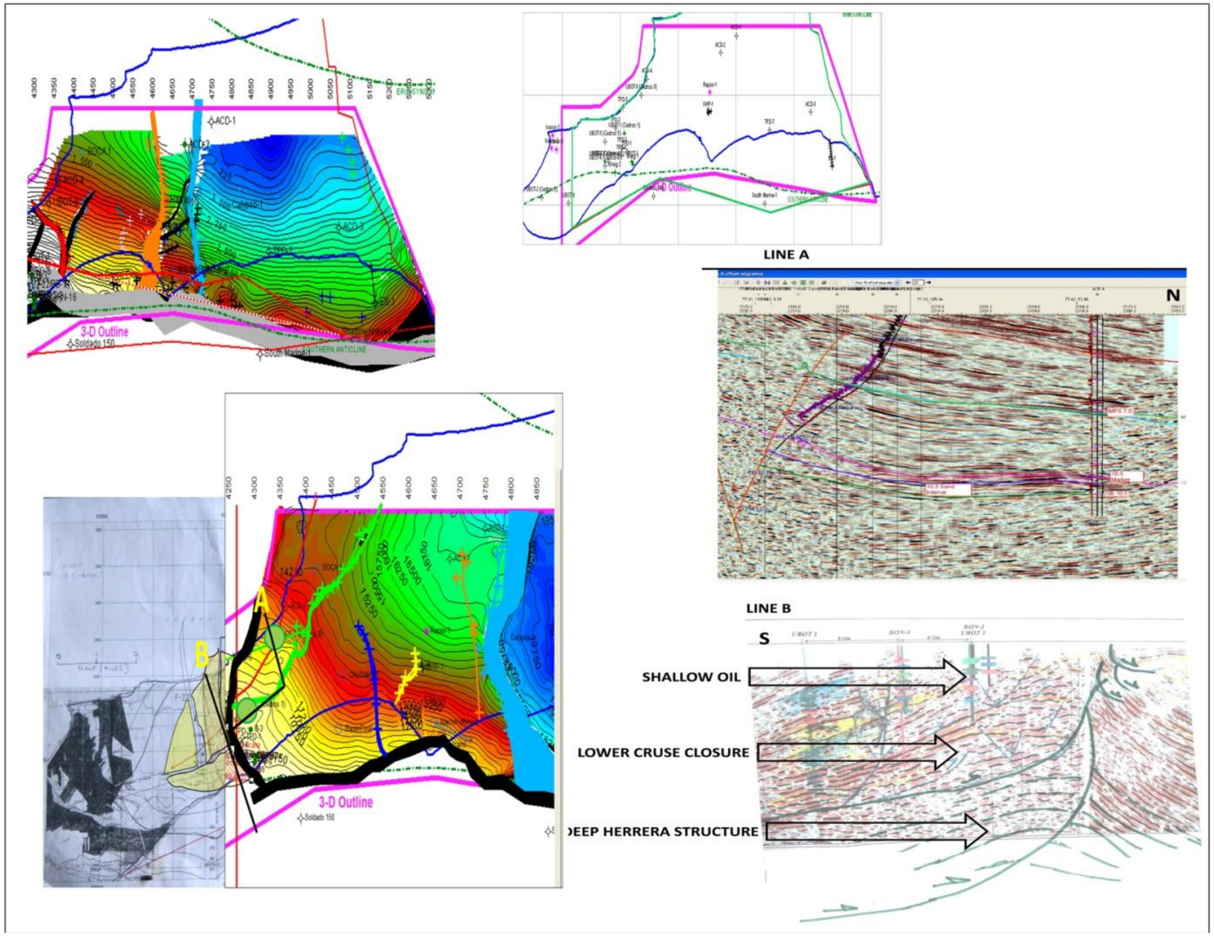

Figure 9. Structure map, 3D structure diagram and seismic sections covering the Cedos Estate area where two discovery wells have been made. Seismic Line A shows the two discovery wells ACD 4 to the north and FRM 1 to the south. ACD 4 found 30 feet of Lengua light oil/condensate pay at 13,000'; FRM 1 found 50 feet of Middle to Lower Cruse light oil pay at 10,000' subsea. Seismic Line B shows a Lower Cruse closure in an upper thrust ramp below shallow oil and a Herrera closure in a deeper structure. West of the north-south wrench fault seismic quality is relatively poor, especially in deeper horizons.

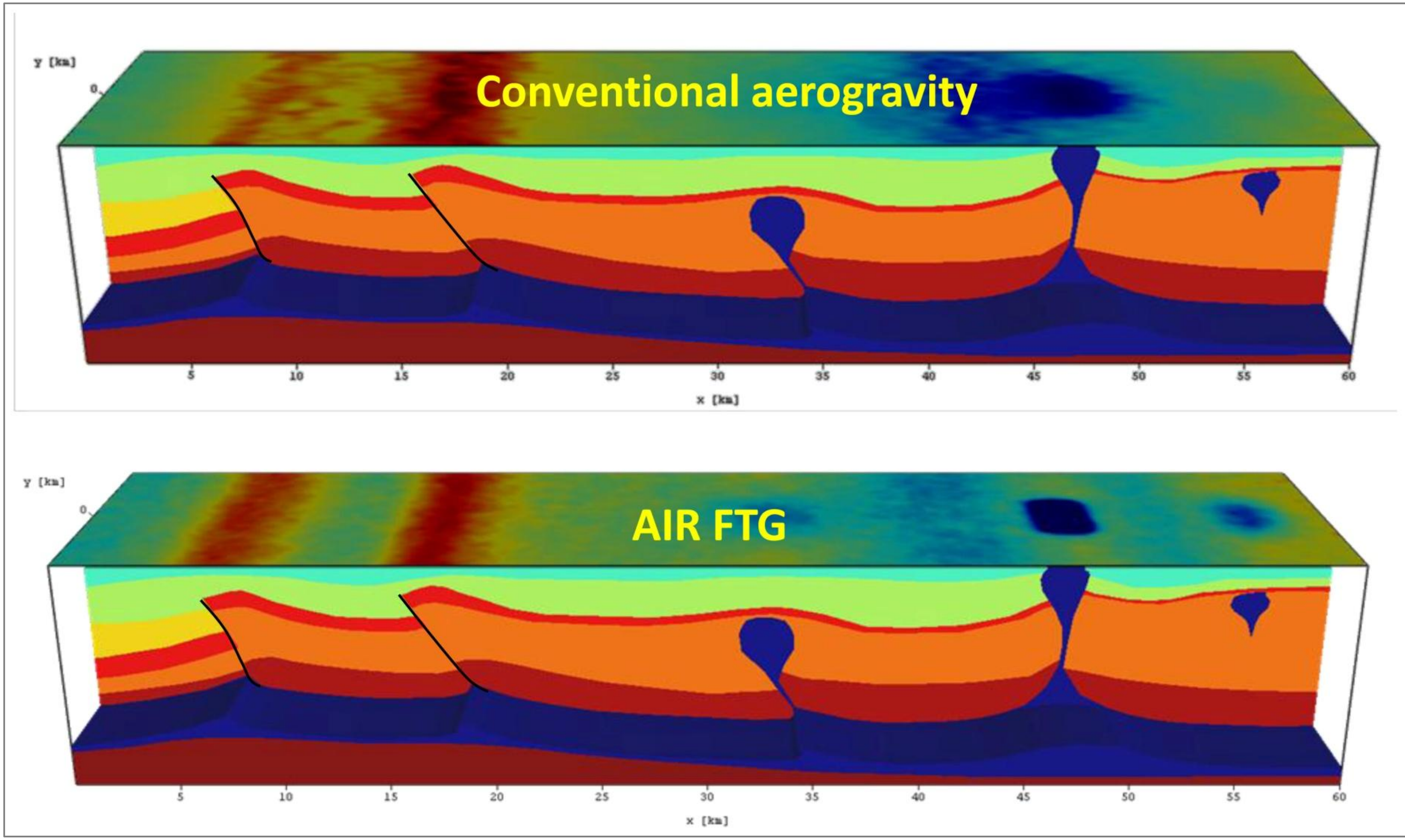

Figure 10. Schematic block diagrams of conventional aerogravity and Air FTG data. Note the higher resolution simulated in the Air FTG data.

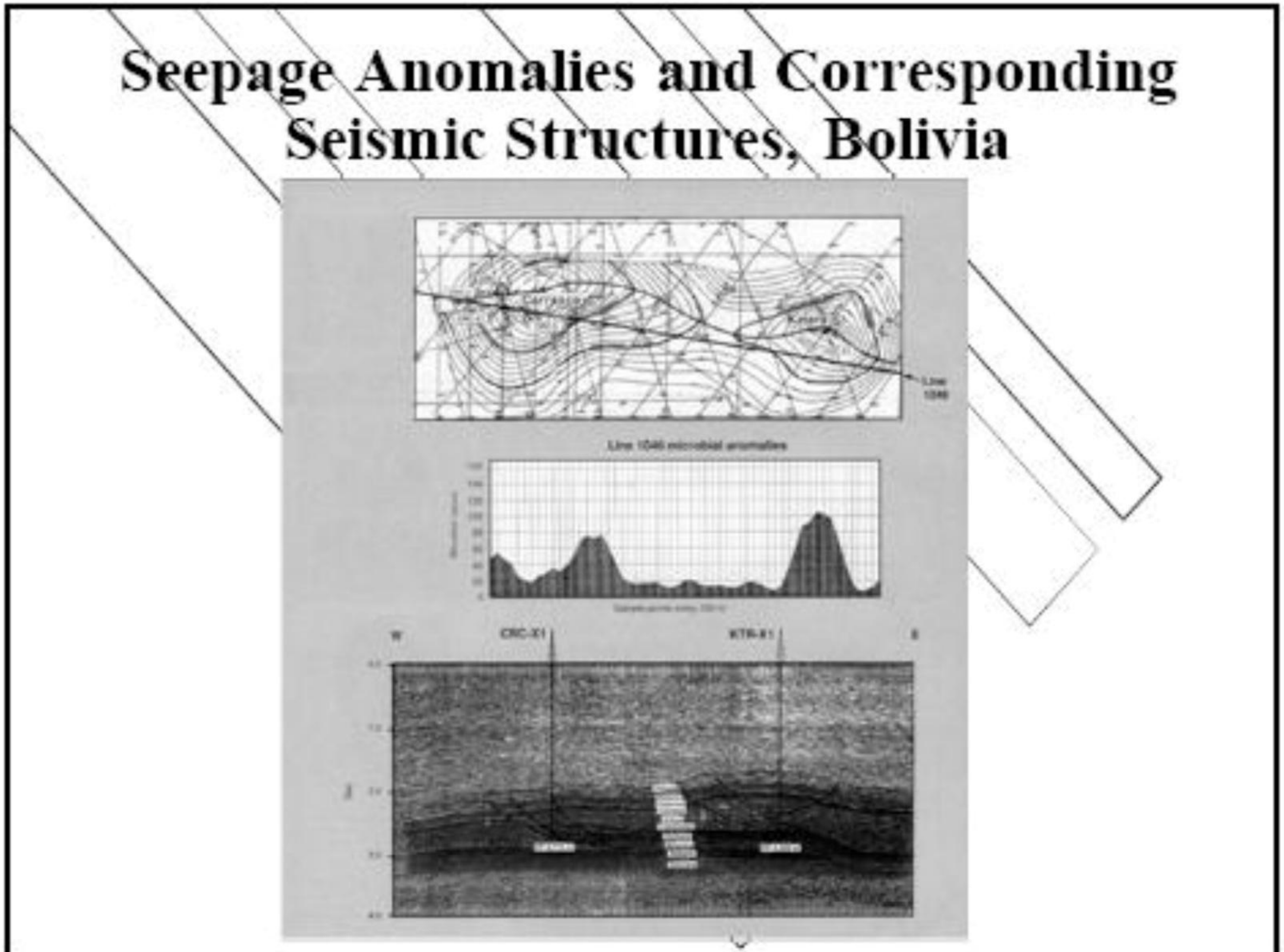

Figure 11. Surface geochemistry has been used successfully in many parts of the world.

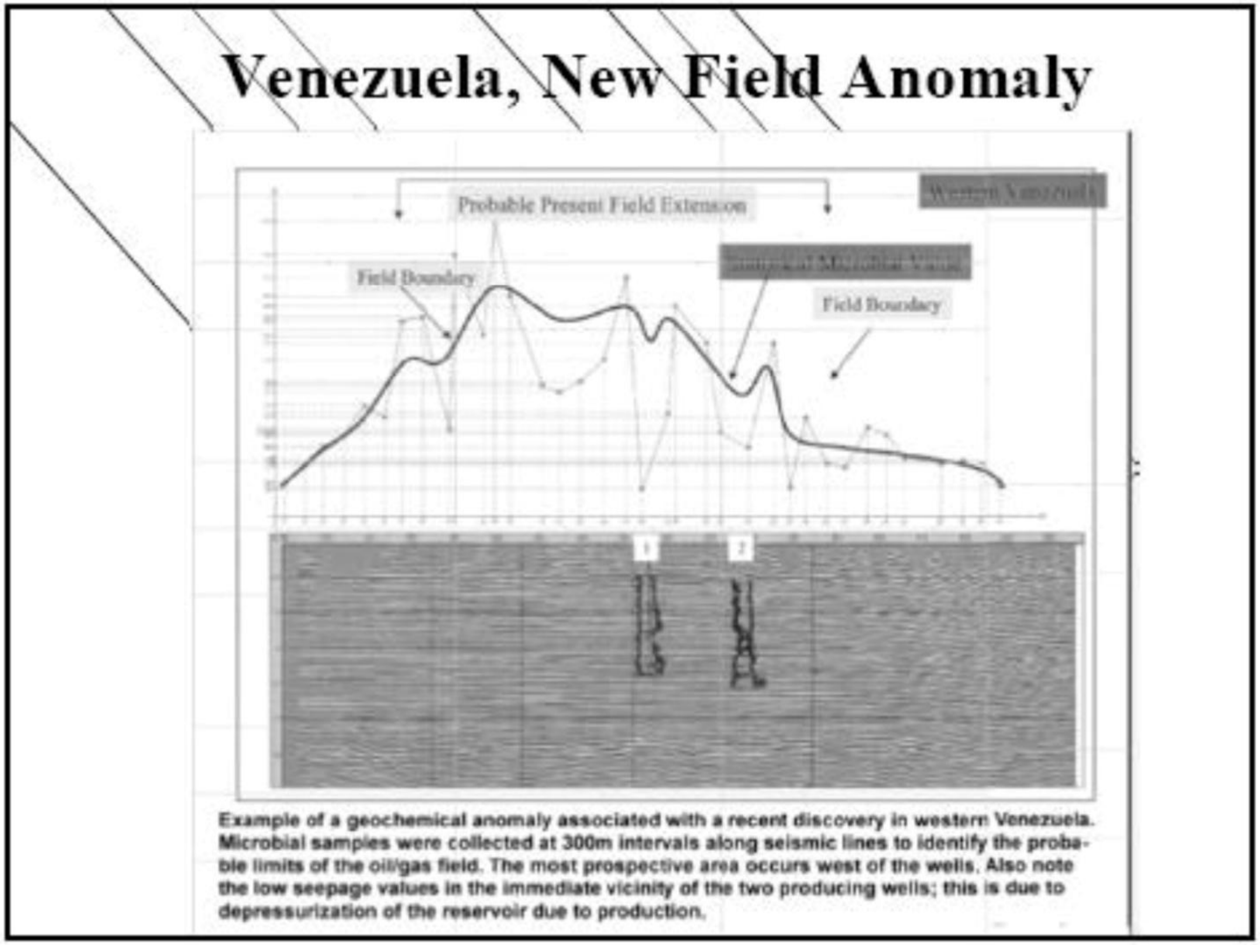

Figure 12. Example of a geochemical anomaly associated with a recent discovery in western Venezuela. Microbial samples were collected at 300 m intervals along seismic lines to identify the probable limits of the oil/gas field. The most prospective area occurs west of the wells. Also note the low seepage values in the immediate vicinity of the two producing wells – this is due to depressurization of the reservoir from production.