

## THE VENEZUELAN HYDROCARBON HABITAT, PART 2: HYDROCARBON OCCURRENCES AND GENERATED-ACCUMULATED VOLUMES

K. H. James\*

*Venezuela's most important hydrocarbon reserves occur in the intermontane Maracaibo Basin and in the Eastern Venezuela foreland basin. Seeps are abundant in these areas. Lesser volumes occur in the Barinas-Apure foreland basin. Most of the oil in these basins was derived from the Upper Cretaceous La Luna Formation in the west and its equivalent, the Querecual Formation, in the east. Minor volumes of oil derived from Tertiary source rocks occur in the Maracaibo and Eastern Venezuela Basins and in the Falcón area.*

*Offshore, several TCF of methane with some associated condensate are present in the Carúpano Basin, and gas is also present in the Columbus Basin. Oil reserves are present in La Vela Bay and in the Gulf of Paria, and oil has been encountered in the Cariaco Basin. The Gulf of Venezuela remains undrilled. The basins between the Netherlands and Venezuelan Antillean Islands seem to lack reservoirs.*

*Tertiary sandstones provide the most important reservoirs, but production comes also from fractured basement (igneous and metamorphic rocks), from basal Cretaceous sandstones and from fractured Cretaceous limestones. Seals are provided by encasing shales, unconformities, faults and tar plugs. There is a wide variety of structural and stratigraphic traps. The Orinoco Heavy Oil Belt of the Eastern Venezuela Basin, one of the world's largest accumulations ( $1.2 \times 10^{12}$  bbl) involves stratigraphic trapping provided by onlap and by tar plugging. Stratigraphic trapping involving unconformities and tar plugging also plays a major role also in the Bolivar Coastal complex of fields along the NE margin of Lake Maracaibo. Many of the traps elsewhere in the Maracaibo Basin were influenced by faulting. The faults played an extensional role during Jurassic rifting and subsequently suffered inversion and strike-slip reactivation. This created anticlines as well as fracture porosity and permeability, and influenced the distribution of sandstone reservoirs, unconformities and related truncation traps. The faults probably also provided migration paths as well as lateral seals. This is very likely the case also in the large, thrust-related traps of the Furrial Trend in Eastern Venezuela. Normal faults, many antithetic*

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*Note: in this paper, MM denotes million; the terms billion and trillion follow American usage (one thousand million and one million million, respectively).*

*to basement dip, provide important traps in the Las Mercedes, Oficina and Temblador complexes on the southern flanks of the Eastern Venezuela Basin. Similar faults seem to control the Sinco-Silvestre complex of the Barinas-Apure Basin.*

*Much of Venezuela's crude (around 1.5 trillion brls original STOIP) has been degraded and is heavy. Perhaps two to three trillion brls of precursor, lighter oil existed. While the known Upper Cretaceous La Luna and Querecual Formations are known to include prolific source rocks, a reasonable generation/accumulation efficiency of 10% implies volumes too large to have come from the reported kitchens. The country's vast reserves are perhaps better explained by recognizing that the present-day basins are remnants of much broader sedimentary areas. The source rocks originally had a much more regional distribution. They suffered widespread, earlier phases of generation that probably charged early-formed traps on a regional scale. These, together with more recent kitchens, provided oil to the present-day accumulations. This history involved long-distance migration and remigration.*

## INTRODUCTION

This paper attempts to provide an overview of the main plays in Venezuela (Figs 1 and 2). Some of these are illustrated in summary fashion. However, much of the information comes from rather old literature. Since many of the classic fields are being reworked, future publications will hopefully provide updated descriptions of them, illustrated with modern seismic/well data and cross-sections.

The paper also suggests that current explanations of the country's enormous reserves are not wholly satisfactory. Earlier phases of generation and entrapment on a regional scale, followed by younger, more local kitchens and entrapment, with remigration from earlier accumulations, may offer a more elegant explanation. If true, this may point towards deeper, untested plays.

Note that this paper is a continuation of Part 1 (James, 2000), which covered the tectonic setting, structure, palaeographic evolution and source rocks of Venezuela. Part 1 provided details of the stratigraphy, geography and geology necessary to understand Part 2, in which I consider the distribution and volumes of hydrocarbons present.

## HYDROCARBON OCCURRENCES

### THE MARACAIBO BASIN

#### Geological occurrence of oil- and gasfields

The Maracaibo Basin (Fig. 1) is defined by the transpressional uplifts of the Venezuelan (Mérida) Andes in the SW, the Serranía de Los Mutilones (or Santander Uplift) in the SE, the Serranía de Perijá in the NW, and the Serranía de Trujillo in the east (Fig. 3a). Physiographically it opens northwards to the Gulf of Venezuela from which it is separated by the major Oca Fault and associated subsurface highs (Fig. 1). The basin deepens SE to the North Andean Foredeep, adjacent to the Mérida Andes.

The basin is structured internally by a southward-opening fan of NE- to north-south to NW-trending faults (James, 2000, Fig. 7). Until recently these were thought to be sinistral strike-slip features. However, the latest interpretations favour their origin as Mesozoic normal faults inverted by Andean compression, and highlight the accommodation of disharmony between deep and shallow structures by the Upper Cretaceous Colón shales (e.g., Roberto *et al*, 1990; Audemard, 1991). The faults probably have a net oblique slip with significant lateral

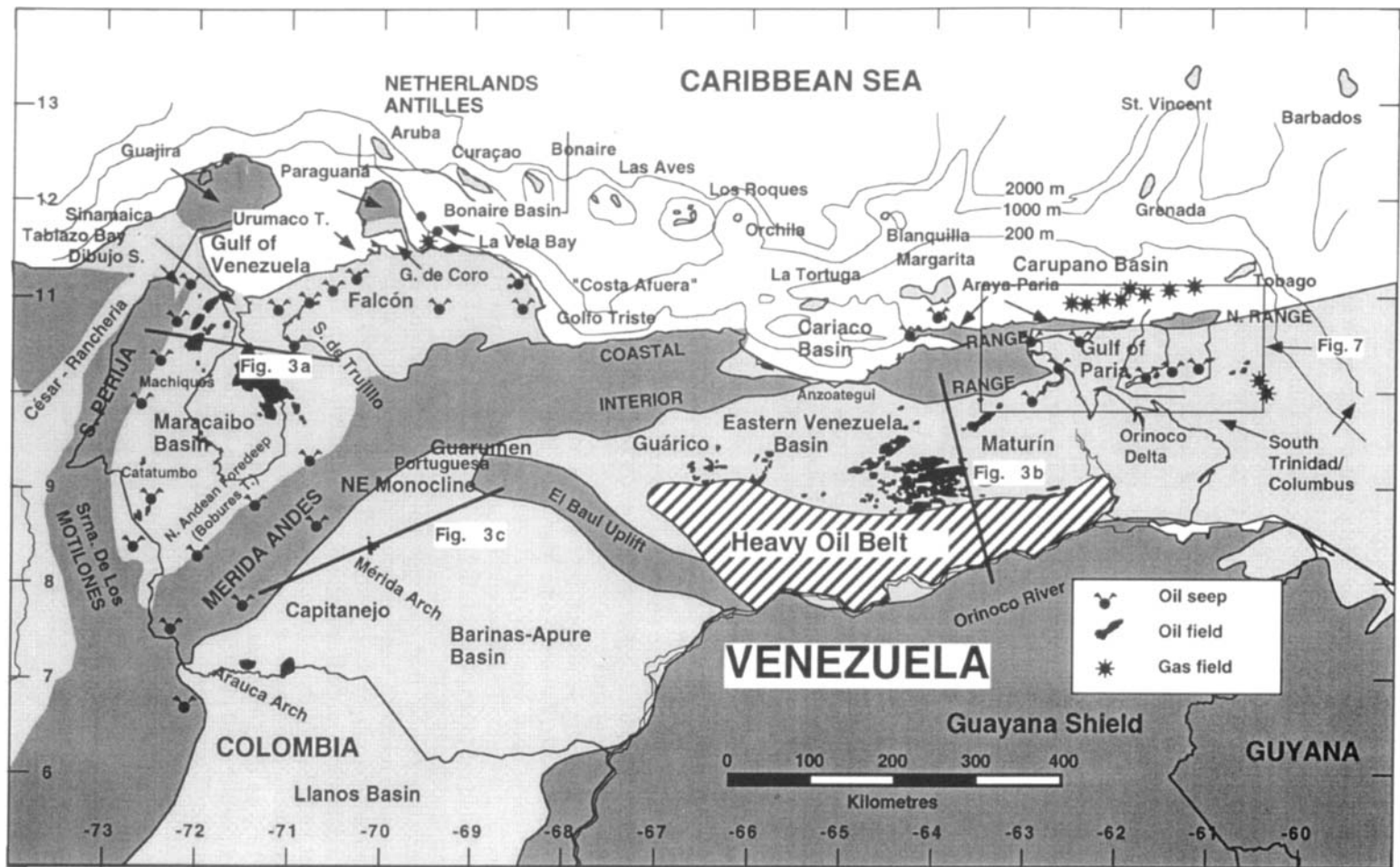


Fig. 1. The main basins, arches and uplifts of Venezuela, together with the distribution of the main oilfields and the locations of seeps. Bathymetric contours at 200, 1000 and 2000m indicate the form of the continental shelf.

displacement. Important fracture porosity is developed along shear zones at fault bends and in associated tight folds.

The Maracaibo Basin has numerous and prolific oil seeps on all flanks, and as in the rest of Venezuela, these focussed early exploratory drilling. Most of the country's production to date has come from this basin, which remains the main producing area in Venezuela. Total oil in place is estimated to be 318 B brls, and production approaches 40 B bbl of oil and 36 TCF of gas. Recoverable reserves are estimated by Petroleos de Venezuela to be  $29 \times 10^9$  brls of oil and 16 TCF gas (Graf, 1998).

In general, the basin contains lighter oil and gas at deep levels and heavy oil at shallow levels, reflecting the loss of light fractions by evaporation, flushing and biodegradation.

Talukdar and Marcano (1994) described two total petroleum systems in the basin. The first contributes 98% of reserves, which have migrated from the Upper Cretaceous La Luna source rock to reservoirs in the Eocene Misoa Formation (50%), the Miocene Lagunillas Formation (44%), the Cretaceous (<5%), and the Miocene La Rosa Formation (<1%), as well as to the igneous and metamorphic basement (<1%) reservoirs. The most efficient system is from the La Luna to the Misoa Formation. This leaks to reservoirs in the Lagunillas Formation. The second system links source rocks in the Maastrichtian-Palaeocene Orocué Group to reservoirs of the same age (47%) and to reservoirs in the Mirador Formation (37%), the Carbonera Formation (11%) and to other Cretaceous (5%) reservoirs. Unlike the former system, a definite source-oil correlation is lacking.

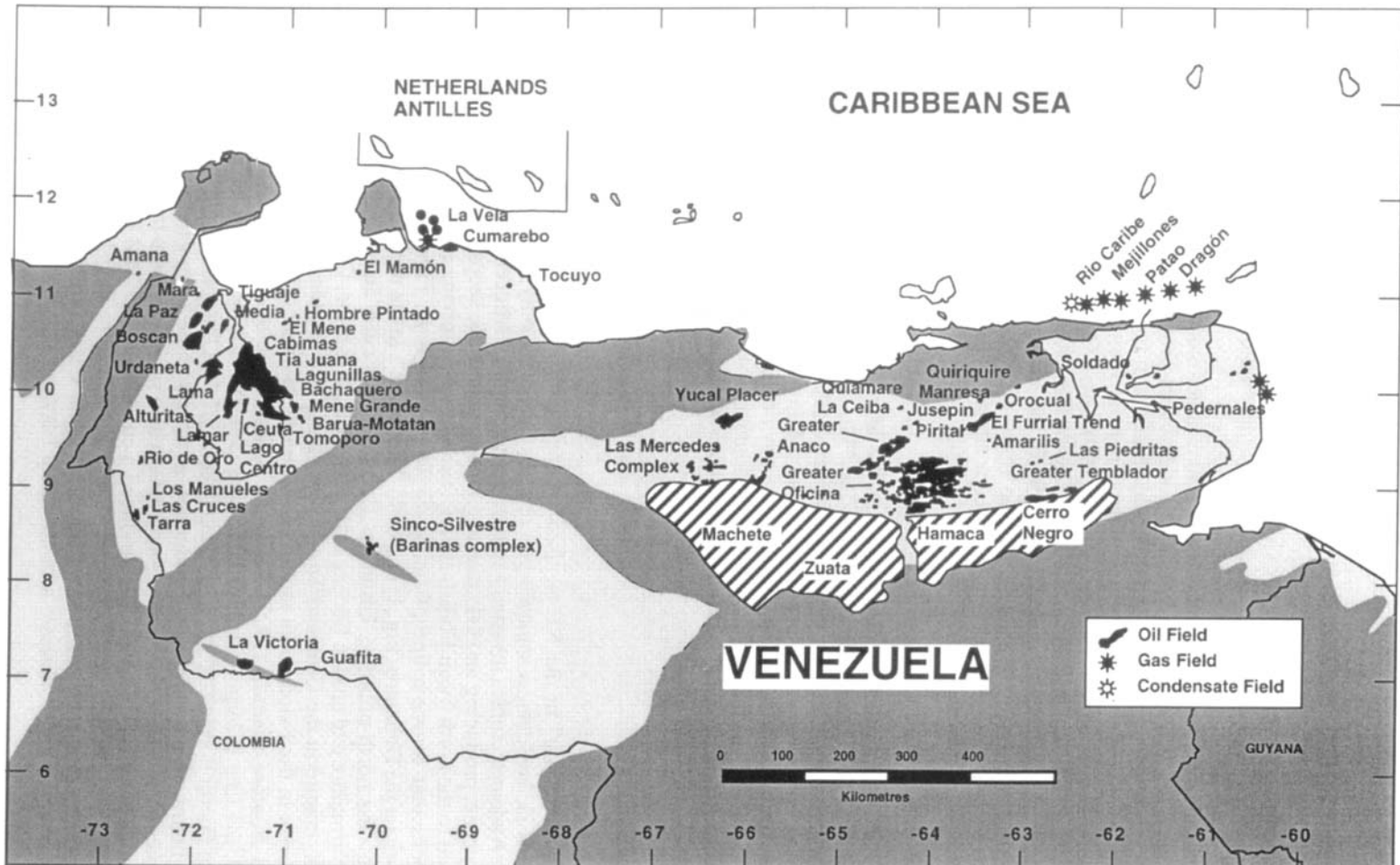
Stratigraphic traps formed by sand pinch-out and truncation are important in the shallow fields in the NE (e.g. the Bolivar Coastal fields from *Cabimas* (discovered in 1917) in the north to *Mene Grande* (1914) in the south: Figs. 2, 3a and 4). Here, crudes reservoirised at depths shallower than around 1,500 m are strongly biodegraded and shallow asphalt forms additional traps (Bockmeulen *et al.*, 1983).

Elsewhere in the basin, the main traps are associated with a family of roughly north-south trending, sinistral strike-slip and reverse faults (Figs. 4 and 5) for example *Tarra*, (discovered in 1916); *La Paz* (1924); *Boscán* (1946); *Urdaneta* (1955); *Centro* (1957); *Lama* (1957) and *Ceuta* (1957). The traps involve structural closure, fault sealing and unconformities. Fault-generated fracture porosity and permeability allow production from otherwise tight Cretaceous limestones and basement rocks.

Eocene and Miocene sandstone reservoirs contain 50% and 40%, respectively, of the Maracaibo Basin's oil (Talukdar and Marcano, 1994). Both possess mainly intergranular porosity. In the Eocene Misoa Formation porosity ranges from 12–28% and the mean permeability is 240 mD. The Miocene Lagunillas and La Rosa Formations have porosities from 10–40% and the mean permeability is 610 mD. Fracturing also enhances the producibility of the Misoa sandstones in the *Barua-Motatán* field.

It is interesting to note that the importance of both porosity-enhancing fractures and of basement potential received some of their earliest recognition in this basin. Fractured igneous and metamorphic basement rocks in the NW produced up to 17,000 b/d in the *La Paz-Mara* fields. Field data show more fracturing in the basement than in the overlying limestones.

Salvador and Hotz (1963) summarized hydrocarbon occurrences in Cretaceous reservoir rocks in Venezuela. Sandstones in the basal Cretaceous Rio Negro Formation have porosities of around 13% in the *Urdaneta* field (Fig.5b). Cretaceous limestone reservoirs have some local matrix porosity and permeability, comprising mollusc packstones and grainstones in the Maraca and Apon Formations. These are poorly predictable, and fracturing provides the main reservoirs at these levels. Fracture density is best in areas of maximum faulting, fault intersections and where rocks have passed through folds (e.g. Bueno and Avila, 1987; Bueno and Pinto, 1994; Apotria and Wilkerson, 1997). Bartok *et al.* (1981) noted that the Albian Cogollo Group has generally poor porosity and permeability (<12%, 3.2 mD) which improves where fracturing has developed in the clean and brittle limestones and sandstones.



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Fig. 2. The main oil- and gasfields of Venezuela.

Horizontal drilling has made fractured source rock in the La Luna Formation a recent exploration target. Seismic anisotropy and 3D seismic data are being used as fracture detection methods. Early-formed fractures are cemented and late-formed fractures are more likely to have preserved porosity. Outcrops in the Sierra de Perijá show two sets of fractures striking around N10-15°E and N50-55°E (Miller, 1962).

The Campanian Colón Shales seal Cretaceous and deeper reservoirs, while overlying/interbedded shales seal younger units. Asphalt forms shallow seals in the Bolívar Coastal fields.

The northern half of the Maracaibo Basin is at a rather mature stage of exploration. In the south, however, the North Andean Foredeep (or Bobures Trough), the Andean front and the Catatumbo area remain poorly explored. While attention in the past focussed upon structural highs, recent exploration successes have tested normal fault traps on the monoclinical rises occurring between these highs (Roberto *et al.*, 1990) where Gámez *et al.* (1997) reported 3 B brls oil in place. Deeper drilling in the *Bachaquero* field has located new pools of lighter (31°API) crude oils (*Oil & Gas Journal*, Feb. 1996). Increasing understanding of the interplay between sedimentation and structure during reservoir deposition, and of the structural complexity of the basin flanks, will lead to major additions to the reserves of this basin.

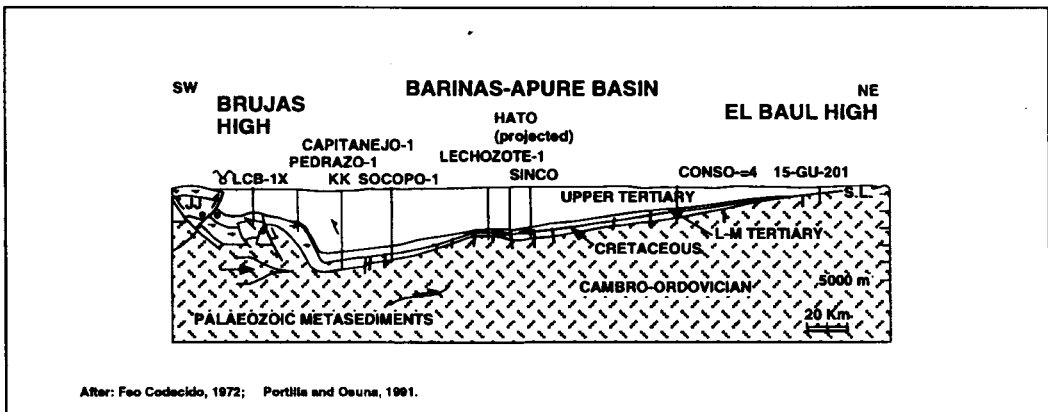
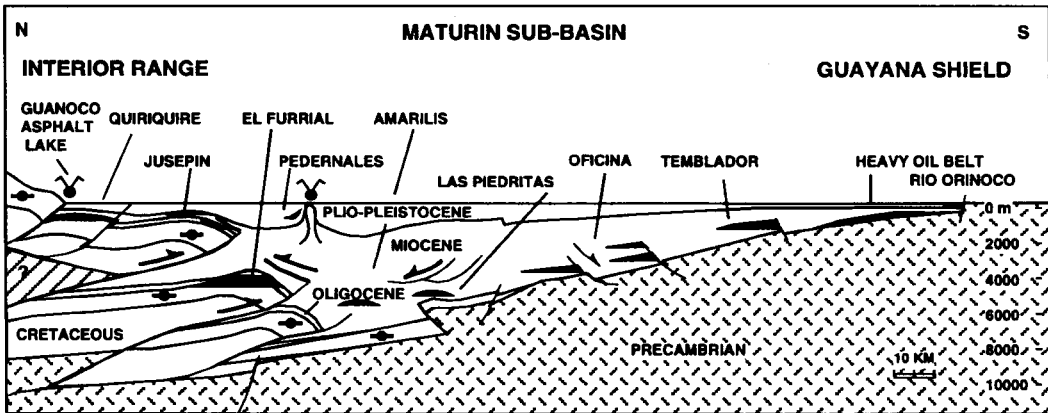
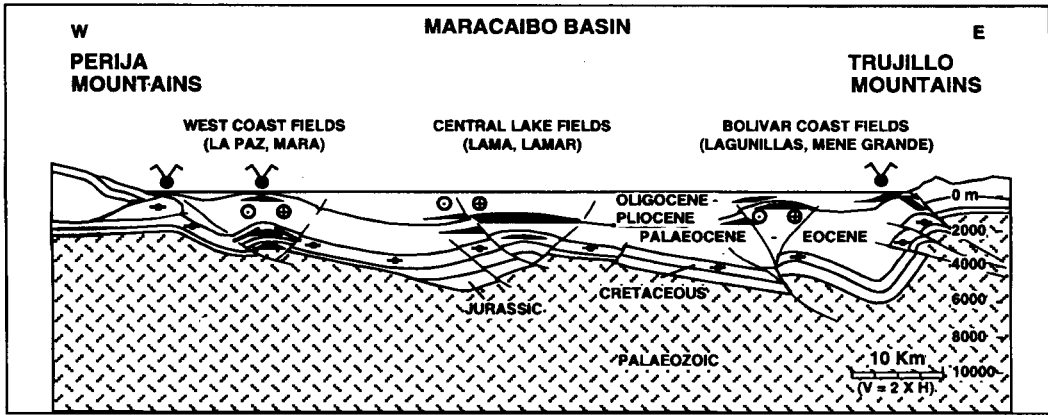
### Dibujo Syncline

This NE-plunging syncline, also known as the Manuelote Syncline, lies at the northern end of the Sierra Perijá range, to the NW of the Maracaibo Basin (Fig. 1), from which it is separated by the Tigre-Perijá fault and an associated (Palmar) basement uplift. Oil occurs at outcrop at the contact between Tertiary rocks and the underlying granite of the uplift, in faults and fractures in igneous rocks, and in the outcrops of the La Luna Formation, the Cogollo Group and Eocene sandstones. Despite this abundance of surface indications, only one field, *Amana* (discovered in 1928), has produced oil (terrestrially sourced) from the northern end of this syncline.

### Falcón Basin

The Falcón "Basin" in the NE is often grouped with the Maracaibo Basin in terms of production. It is, however, a separate geological entity with only a minor, Tertiary-sourced production. Andean tectonics inverted a middle Eocene-middle Miocene pull-apart basin during the late Miocene, producing an ENE-trending anticlinorium. No seeps occur on this structure. It is bounded to the north by an ENE-trending fault system involving locally preserved, viable Tertiary rocks that source a line of fields (*El Mene – Tiguaje*, Figs. 2 and 5c) and seeps. Further north lie the Dabajuro (Fig. 1) and Coro "platforms", in the west and east, respectively, separated by the north-plunging Urumaco Trough. These carry immature Miocene–Recent cover on overmature and eroded Eocene and older rocks. A marine, Oligocene-lower Miocene source rock, mature in the Urumaco Trough, fed the updip, abandoned *Mamón* field.

Discoveries in the Falcón area include *El Mene de Mauroa* (discovered in 1921), *Media* (1929) and *Hombre Pintado* (1927) fields, all drilled close to seeps (Halse, 1947). At the *Mene* field, the trap is largely stratigraphic (Fig. 5c). Oil occurs in sand lenses of the Mio-Pliocene La Puerta Formation and in truncated sands of the Oligocene Agua Clara Formation, above and below an unconformity. Production at *Media* came from sandstones in the Agua Clara Formation, sealed by faults. *Hombre Pintado* also produced from the same interval; but here the trap is anticlinal. These fields produced a cumulative 107 MM brls of waxy, marine-terrestrial oil. The source rock is Eocene in age according to Boesi and Goddard (1991), though earlier studies recognized the Oligocene Agua Clara Formation as the most likely source. Biomarker studies indicate a relationship between seeps at *Mene de Mauroa* in the



After: Feo Codecido, 1972; Portillo and Osuna, 1991.

Fig. 3. Schematic cross-sections of (a) the Maracaibo Basin; (b) the Maturin sub-basin; and (c) the Barinas-Apure Basin, illustrating the main plays. Oil accumulations are shown in black. The sections are composites in which the plays are projected into the same plane.

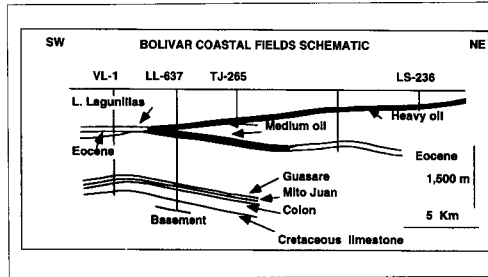


Fig. 4a. Bolivar Coastal fields (after Wallis, in Mencher et al., 1953).

**Trap:** Regional faulted monocline, dipping SW, Eocene unconformity above truncated Eocene and older reservoirs. Asphalts and pinch-out seal shallow reservoirs. Seeps.

**Reservoir/seal:** Sandstones in the Oligo-Miocene La Rosa and Miocene Lagunillas Formations. **Source/kitchen:** La Luna Formation matured in North Andean foredeep since the Miocene, matured in the Eocene NE of the basin (oil parked over Eocene centre basin high, remigrated to the NNE during basin subsidence). **Hydrocarbons:** 11-34° API; 28,200 MM bbl reserves.

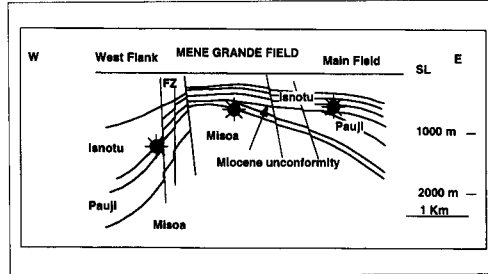


Fig. 4c. Mene Grande field (after Fichter and Renz, in Mencher et al., 1953).

**Trap:** Asphalt plugging and pinch-out of Miocene sandstones updip on south-plunging anticline; fault trap; unconformity trap at Eocene level. Abundant seeps. **Reservoir/seal:** Eocene Misoa Fm sandstones, 12% porosity, 1mD. Miocene Isnotu Fm sands, 26% porosity, 23mD. **Source/kitchen:** La Luna Formation in the North Andean Foredeep, Miocene-Recent generation; remigration of Eocene generated oils. **Hydrocarbons:** Heavy oil in shallow and lighter oil in deeper reservoirs, average 20° API, 800 MM bbl reserves.

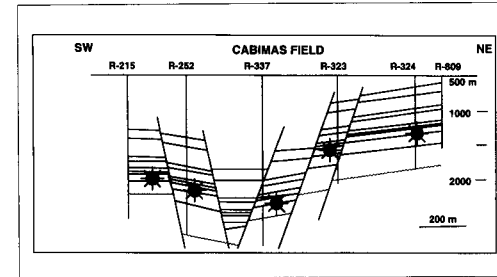


Fig. 4b. Cabimas field (after Arata et al., 1985).

**Trap:** SW plunging anticline/syncline erosionally truncated to NE and compartmented by NS trending normal faults.

**Reservoir/seal:** Sandstones of the post-Eocene Icoatea, La Rosa and Lagunillas Formations.

**Source/kitchen:** Cretaceous La Luna Fm, mature in the north Andean foredeep.

**Hydrocarbons:** Heavy, biodegraded, 530 MM bbl reserves.

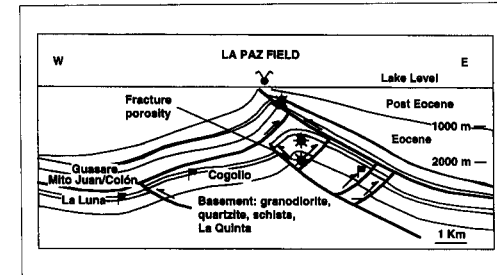


Fig. 4d. La Paz field (structure after Audemard, 1991):

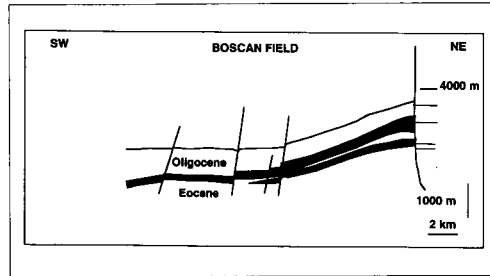
**Trap:** Anticline associated with thrusts detaching in igneous/metamorphic basement and in the Colón Fm Shale; sinistral movement also involved.

**Reservoir/seal:** Fractured basement and Cogollo/La Luna limestones (1.2-2.8%), Palaeocene Guasare Fm (22%) and Eocene Misoa Fm (22%) sandstones, sealed by light basement top, basal sandstone and marl, Cretaceous Colón Fm shales, Tertiary shales.

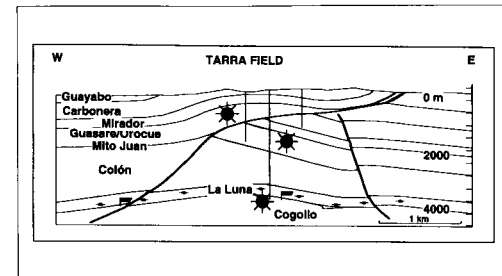
**Source/kitchen:** La Luna Fm, Eocene kitchen to NE, Miocene-Recent kitchen to east, south and SE.

**Hydrocarbons:** 34° API oil at up to 11,700 bbl/d (mean 3,600, up to 17,000 bbl/d in Mara field) from fractured basement, 13-30° API from Tertiary. La Paz recoverable 1 billion bbl.

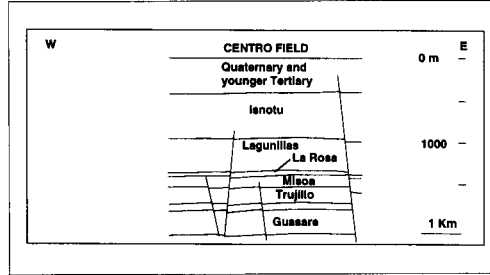




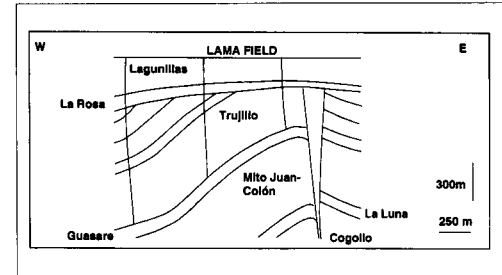
**Fig. 4e. Boscan field** (after Richmond Exploration, in Smith 1962).  
**Trap:** Homocline, dipping SW, cut and sealed by Boscán Fault, truncation of sandstones at the Eocene unconformity.  
**Reservoir/seal:** Concepcion, Icotea and La Rosa Fm sandstones; Eocene fluvio-deltaic sandstones.  
**Source/kitchen:** La Luna Fm, early mature in the vicinity of the field.  
**Hydrocarbons:** Low maturity, sulphur rich, mild bacterial alteration, 11-12° API, produced 800 brl; 2,470 MM brl reserves.



**Fig. 4f. Tarra field.**  
**Trap:** Thrust-generated anticline of Tarra-Los Manuales complex. Tertiary structure disharmonic to Cretaceous (accommodation in Colón shales).  
**Reservoir/seal:** Aptian-Albian Aguardiente and Apon Fm limestones (6%, 3000mD fracture permeability) and Palaeocene Catatumbo sandstone (18.5%) sealed by Colón shales, Mirador shales and faults.  
**Source/kitchen:** Cretaceous La Luna and Tertiary Orocue Fms, mature in the North Andean foredeep from Miocene time.  
**Hydrocarbons:** 38-51° API, 137 MM brl UR, solution gas drive.



**Fig. 4g. Centro field** (after R.B.Scott, in Smith, 1952):  
**Trap:** NE-trending anticline, fault seal and facies changes.  
**Reservoir/seal:** Miocene La Rosa Fm sandstones.  
**Source/kitchen:** La Luna Fm, matured in the Eocene to the NE. In the Miocene – Recent to the south.  
**Hydrocarbons:** 35° API, 2000 MM brl reserves.



**Fig. 4h. Lama field.**  
**Trap:** NNE-trending anticline cut by faults; unconformity truncation.  
**Reservoir/seal:** Lower Eocene “C” and “B” sandstones, porosity 24% perm. 300 mD, minor contributions from fractured Cretaceous Cogollo limestones, Palaeocene Gausare Fm limestones and Miocene Santa Barbara Fm sandstones.  
**Source/kitchen:** La Luna Fm, matured during the Eocene in the NE, in the Miocene-Recent in the south.  
**Hydrocarbons:** 32-40° API, undersaturated, EUR 3,500 MM brl proven, 9,700 MM brl STOIPP.

**Fig. 4. Field summaries, Maracaibo Basin.**

west and *Mene Cosme* in the east, and the Oligo-Miocene Guacharaca Formation and the Miocene Agua Salada Group (Ollo *et al.*, 1994). The *Cumarebo* field (1931) produced gas and condensate from Miocene sandstones in a north-vergent, thrust-related anticline on the southern shoreline of La Vela Bay. This field probably is related to discoveries on a basement high that trends across the adjacent Bay. These contain hydrocarbons in fractured basement and in Miocene carbonates and sandstones. To date, they remain undeveloped. The source rock in this area is thought to be the same, marine Oligo-Miocene section as in the Urumaco Trough.

Suter (1947) described the structure at the abandoned *Mene de Acosta* field as an asymmetric NE-trending anticline on which only the south flank had been productive. The field was discovered in 1925 by surface mapping and seeps. Pitch and 18°API oil had been observed in a river cut at Mene and Menecito, and gas was visible in the wet season.

## THE EASTERN VENEZUELA BASIN

### Geological occurrence of oil-and gasfields

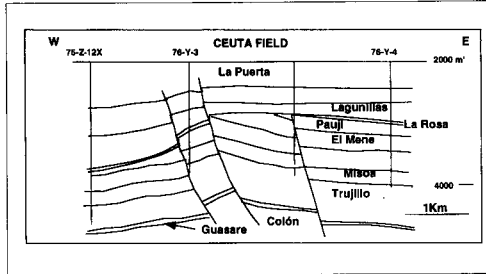
The asymmetric, Eastern Venezuela Basin runs ENE along the north flank of the Proterozoic Guayana Shield (Fig. 1). It deepens northwards from the Shield towards its northern margin (Fig. 3b), which comprises uplifts formed by the Cretaceous - Palaeogene sedimentary rocks of the Interior Range and the Jurassic - Cretaceous metasediments of the Coastal Ranges. The basin is tilted to the east. Uplift and erosion occur in the west, while subsidence continues in the east. Sedimentary thicknesses are thought to exceed 12 km in the northern foredeep, but the exact depth to the basement in the northern part of the basin has not yet been verified. The degree to which the Interior Range overrides the foredeep also is unknown and the thickest part of the Tertiary section, below the Amacuro Delta, is poorly explored.

This basin had an important early production history from fields such as *Quiriquire* (discovered in 1925), *Pedernales* (1933), *Jusepín* (1938) and *Orocual* (1933), together with the fields of the Greater Mercedes (1941), Anaco (1937) and Oficina (1937) areas (Figs. 2 and 6). Deep drilling in the fold-and-thrust belt revitalized enthusiasm in the early 1980s, with the discovery of the Furrial trend (1983). At the same time, delineation of the Heavy Oil Belt resulted in the realization that this is possibly the world's largest oil accumulation. The basin has produced some 13 B bbl of oil, considerably less than the Maracaibo Basin. However, the area is assuming increasing importance as the Furrial trend accumulations are developed and as various projects to exploit the Heavy Oil Belt move ahead.

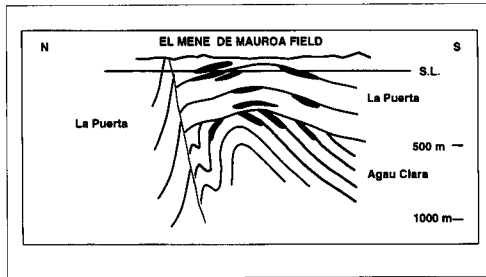
The El Baúl Uplift or Arch in the west separates the Eastern Venezuela Basin from the Barinas-Apure Basin (Fig. 1). The arch is not completely covered by Cretaceous sediments and the Eocene is absent. It was completely covered by Oligocene sediments, but towards the end of the Miocene the Oligocene-Miocene section was partly eroded. Palaeozoic igneous-metamorphic rocks and Triassic-Jurassic volcanics are exposed locally today. The area north of the Arch has been referred to as the Guarumen Basin.

The Eastern Venezuela Basin is sub-divided into the western (Guárico) and eastern (Maturín) sub-basins by the Anaco-Altamira Fault. This had considerable synsedimentary activity and now supplants the Urica Fault, which was originally taken as the boundary between the sub-basins. The area south of the Cariaco embayment is sometimes referred to as North Anzoátegui, and the zone of fields along the Anaco Fault is known as the Greater Anaco Area.

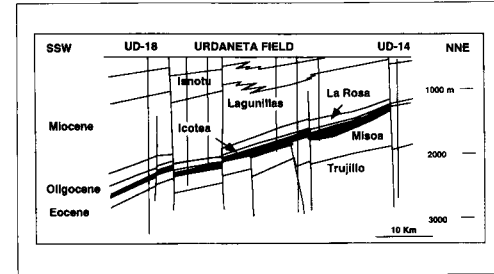
Lilliu (1990) defined the Frontal Deformation Alignment, south of which no compressional deformation is seen, which runs approximately 50 km south of the town of Maturín. The Maturín Foreland, north of the alignment, is a sedimentary basin that continues northwards as far as the Interior Range foothills. Like the Interior Range, this basin is characterized by thrust anticlines separated by transcurrent faults. The Maturín Foredeep, characterized by normal faulting, lies between the deformation front and the Guyana Shield.



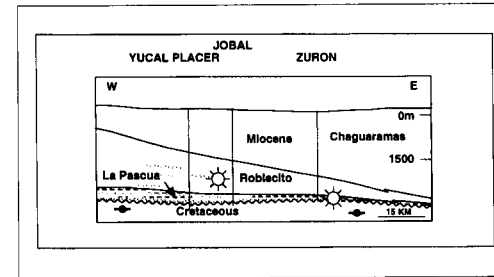
**Fig. 5a. Ceuta field.**  
*Trap:* Pueblo Viejo anticlinal structure, Pueblo Viejo, Ceuta and West Boundary Faults.  
*Reservoir/seal:* Eocene Misoa Fm lower "B" sandstones (10-17%), and Oligo-Miocene La Rosa and Lagunillas Fm sandstones (20-30%).  
*Source/kitchen:* La Luna Fm, matured in Eocene in NE. Miocene – Recent in the south.  
*Hydrocarbons:* 8-38° API, EUR 1,402 MM brl.



**Fig. 5c. El Mene de Mauroa field (after Fichter and Renz, in Mencher et al. 1953):**  
*Trap:* Unconformity cut-off and sand lenses in faulted anticline with seeps.  
*Reservoir/seal:* Mio-Pliocene La Puerta and Oligocene Agua Clara Fm sandstones.  
*Source/kitchen:* Tertiary humic OM in Agua Clara Fm, Late Miocene – Pliocene generation?  
*Hydrocarbons:* 32° API oil.



**Fig. 5b. Urdaneta field.**  
*Trap:* NE-SW trending high cut by parallel and orthogonal faults, oil is associated with the Eocene unconformity.  
*Reservoir/seal:* Eocene Icoltea and Misoa Fm sandstones above and below the Eocene unconformity, porosities up to 32%, 5-2750 mD.  
*Source/kitchen:* La Luna Fm, matured in the Eocene in NE, Miocene-Recent in the south.  
*Hydrocarbons:* 12° API, very heavy, viscous, sulphur-rich, 1615 MM brl reserves.



**Fig. 5d. Yucal-Placer field.**  
*Trap:* Pinch-out of turbiditic sandstones, drape over low-relief structures associated with thrust fault.  
*Reservoir/seal:* Oligocene La Pascua and Roblecito Fm sandstones (porosity 5-18%).  
*Source/kitchen:* Marine amorphous kerogen in the Cretaceous La Cruz, Infante and Guaninita Formations in the northern part of the Guárico sub-basin.  
*Hydrocarbons:* 8 TCF gas, C<sub>1</sub>-C<sub>2</sub>, CO<sub>2</sub>, H<sub>2</sub>S.

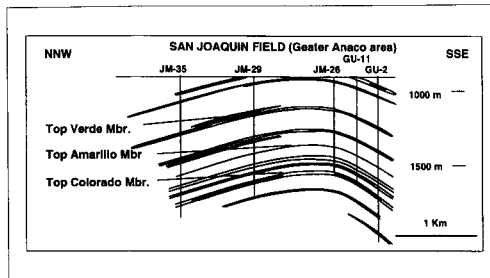


Fig. 6a. San Joaquin field (after Mencher et al., 1963).

**Trap:** Elongate dome, one of a series of *en échelon* and strike-slip offset surface features associated with the SE-verging NE-striking Anaco Thrust. Steep SE flank, gentle NW flank. No seeps. High temperatures.

**Reservoir/seal:** Oligocene, lenticular Oficina Fm sst (18-26%, 50mD) and Merecure Fm sst (15-20%, 100-300 mD); interbedded and overlying shale seals; thin sands overpressured.

**Source/kitchen:** Mixed, Cretaceous Querecual Fm and Tertiary Merecure and Oficina Fm. Mio-Pliocene generation in Espino Graben.

**Hydrocarbons:** Waxy, 33-47° API, up to 60°, 358 MM brl reserves, gas caps.

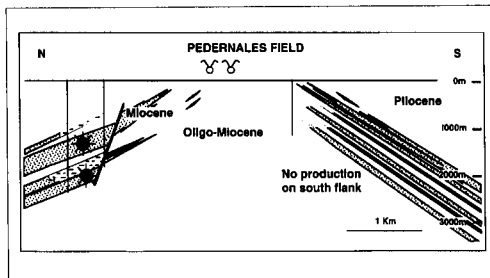


Fig. 6c. Pedernales field.

**Trap:** Stratigraphic traps on flank of clay diapir (Oligo-Miocene Carapita Fm) generated by Andean compression.

**Reservoir/seal:** Miocene La Pica Fm turbidites to deltaic channel sandstones (27%, 300 mD), maximum thickness 250m, sealed by interbedded and overlying shales.

**Source/kitchen:** La Luna and San Antonio Fm, matured in Late Miocene to Recent kitchen in the north of the Maturin Basin.

**Hydrocarbons:** 18-22° and 26-31° API oil, 58 MM brl produced, 547 MM brl STOHP. extension STOHP 600 MM brl, 300 MM brl reserves.

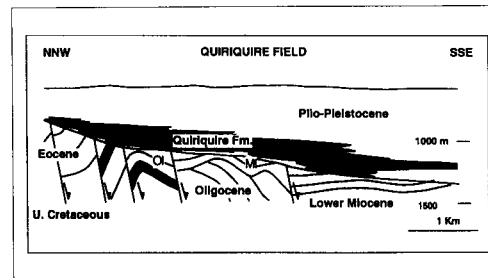


Fig. 6b. Quiriquire field.

**Trap:** SE-dipping monocline with lateral pinch-out and deeper faulted anticline. **Reservoir/seal:** Pliocene Quiriquire Fm. alluvial fan sandstone/conglomerates, poorly sorted, 18% porosity, 100-11,000 mD, sealed by lateral shale-out and gilsonite, also Oligocene, main deeper reservoir (11% porosity, fractured), Eocene Los Jabillos, Caratas and Vidono and Cretaceous San Antonio Fm sandstones.

**Source/kitchen:** Cretaceous Querecual-San Antonio Fm, upper, matured Late Miocene-Holocene beneath the main thrusts.

**Hydrocarbons:** 750 MM brl produced 12-28° API oil, gas and condensate (55-56°) at deeper levels (none produced, Los Jabillos is best known). 812 MM brl and 545BCF reserves: 4-5 MM brl STOHP.

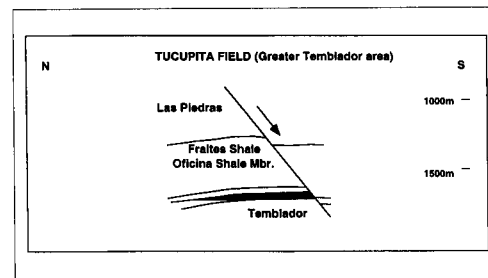


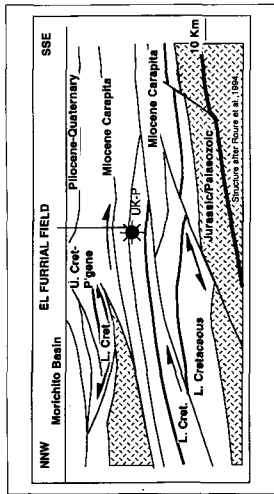
Fig. 6d. Tucupita field (after Mencher et al., 1963).

**Trap:** Down-to-south normal fault on regional foreland ramp.

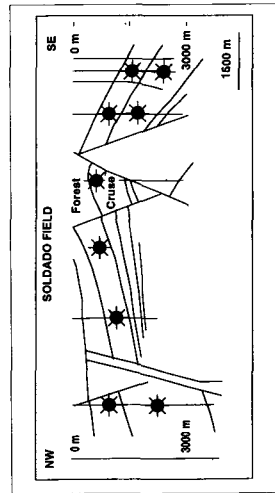
**Reservoir/seal:** Oligocene Oficina Fm sandstone, sealed by overlying Oficina shales.

**Source/kitchen:** Querecual Formation, matured to north during Miocene.

**Hydrocarbons:** 95 MM brl reserves.



**Fig. 6e. El Furrial field (structure after Roure et al. 1994).**  
**Trap:** Fault-bend fold, 10 x 8 km, 915m closure, part of 100km long feature segmented by tear faults, far mat forms north and south limits, *décollement* in shales of the Miocene Carapita Fm.  
**Reservoir/seal:** Oligocene (“Naricua”) deltaic sandstones (13-17%) and Cretaceous San Juan sandstone (9-11%), sealed by Cretaceous interbedded and Miocene overlying shales.  
**Source/kitchen:** Querecual-San Antonio Fm, upper Cretaceous, matured late Miocene-Holocene beneath the main thrusts.  
**Hydrocarbons:** 1690 MM bbl reserves, 26.5° API.



**Fig. 6f. Soldado field.**  
**Trap:** Flower anticline associated with sinistral Soldado Wrench Fault.  
**Reservoir/seal:** Pliocene Forest and Mio-Pliocene Cruso Fm deltaic sandstones, sealed by overlying interbedded shales.  
**Source/kitchen:** Cretaceous Naparima Hill Fm in the Columbus Basin or below the southern Gulf of Paria.  
**Hydrocarbons:** The Soldado field complex has produced more than 500 MM bbl 24-34° API oil plus gas.

To the east of the Maturín area (Fig. 1), the Eastern Venezuela Basin deepens into the Gulf of Paria towards Trinidad and the Atlantic Shelf. The Gulf of Paria (*see below*) is a downfaulted area that links eastern Venezuelan and Trinidadian geology below Mio-Pliocene sediments. The Gulf opens to the Atlantic to the SE of Trinidad via the Serpent’s Mouth channel. More than 14 km of mainly Miocene to Recent sediments are present SE of Trinidad (Erich and Barrett, 1990).

The southern flank of the Eastern Venezuela Basin is structured by a conjugate system of NW- and NE-trending normal faults that downthrow preferentially to the south (Fig. 3b) (James, 2000, Fig. 7). These are thought to be a response to fold-and-thrust loading in the north, generated by transpression between the Caribbean and South American Plates. Compressive stresses affect the basin at least as far as the diapiric trend that runs from Maturín to Trinidad and have produced the inverted structures of the Piedritas trend. In the eastern part of the Maturín sub-basin, north-trending, eastward-dipping listric faults affect the thick Miocene-Pleistocene section.

### The Guarumen Basin

This little-explored and apparently barren area, strongly overthrust by nappes, lies at the northern end of the El Baúl Arch where it forms a link between the Guárico sub-basin and the Barinas-Apure Basin (Fig. 1) The Basin is separated from the Guárico sub-basin by the north-trending subsurface El Pao High.

There are no seeps and no fields in this area. A stratigraphic well, *Guarumen-1s*, tested a seismic interpretation that showed a sedimentary, autochthonous foreland basin beneath the nappes (Chigne, 1989). The well penetrated Palaeocene-Eocene flysch containing large Cretaceous olistostromes in the allochthon, a Barinas-type middle Eocene-Oligocene section in the autochthon and bottomed in Palaeozoic basement. The well recorded only minor shows of formation gas. A Cretaceous source section was absent as a result of non-deposition, erosion or fault cut-out.

### The Guárico sub-basin

One oil seep and three gas seeps have been reported from the Guárico sub-basin (Renz *et al.*, 1958). There are no surface indications of the field complexes occurring further south, which include part of the Orinoco Heavy Oil Belt and fields of the huge Greater Mercedes Area. Cretaceous source rocks in the north of the area are thought to have entered the oil window in the Oligocene and are now gas prone.

In the northern Guárico sub-basin, the *Yucal-Placer* field (Fig. 5d, discovered in 1948) which has reserves of 8TCF of thermal gas (mainly methane) has an element of stratigraphic trapping provided by southward shale-out of Oligocene barrier-island and turbidite sandstones assigned to the Roblecito and La Pascua Formations (Aymard *et al.*, 1985). These are the Guárico sub-basin equivalents of the Maturín sub-basin Los Jabillos and Caratas Formations, respectively (James, 2000, Fig. 8b). Porosities are 5-18% and 8-18%, respectively. Shales in the Roblecito Formation and the upper part of the La Pascua Formation provide seals. Daal and Lander (1993) noted temperature gradients here of up to 4.2°C/100m here, among the highest in the Eastern Venezuela Basin.

In the Greater Las Mercedes Area (1941), La Luna-sourced, moderately mature oil and gas are trapped by antithetic normal faults. Oligocene La Pascua and Roblecito Formation sandstones (12-22% porosity) and the lower Miocene Chaguaramas Sandstones (20-25% porosity) form the main reservoirs. There is also minor production from fractured carbonates of the Cretaceous La Cruz Member of the Tigre Formation. Las Mercedes field oils (25-35°API) show no significant vertical or lateral gravity distributions (Talukdar, 1992).

### Northern Anzoategui

This area lies in the eastern part of the Guárico Sub-basin (Fig. 1). Here, the greater part of the Coastal and Interior Ranges collapsed during pull-apart that created the Cariaco Basin in the Late Miocene. Only the southernmost folds and thrusts remain to crop out onshore. The area just to the south of these is the deepest part of the Guárico sub-basin and is probably an active kitchen today. One seep occurs near the coast just east of Puerto La Cruz, in the NE of the area.

In the northern part of the area, fields such as *Quiamare* (discovered in 1942, 30-50°API), *La Vieja* (1950, 12-37°API), *Cerro Pelado* (1951, 34-40°API) and *La Ceiba* (1946, 30-40°API) produce from Miocene Oficina and Merecure Formation sandstones (7-11% porosity) in anticlinal traps. Most production comes from the Oficina Formation, using gas and water drive (Galeazzi *et al.*, 1996). According to Flores and Barbato (1990) fracture porosity in the dense glauconitic, San Antonio limestone (1.5% porosity), allows condensate to be produced.

Deeper prospectivity related to the fold and thrust belt should exist in the north, and further prospectivity may be present in compressional structures within or adjacent to the Urica and Anaco fault systems. This play was tested recently by the *TAG-1* well which produced oil from thrust lower Miocene sandstones at rates of up to 16,000 b/d.

## The Anaco Area

Fields in the Anaco area — *San Joaquin* (Fig. 6a), *El Roble*, *Guario*, *Santa Rosa* (discovered in 1937) — are located in a narrow zone of asymmetric anticlines, expressed at the surface, above the N50°E-trending, NW-dipping Anaco Fault. The trend is cross-cut by NW trending strike-slip faults. The Anaco Fault is interpreted to have been active as a reverse fault in the Late Miocene-Pliocene, but the Oligo-Miocene section thickens across the fault from east to west, indicating downthrowing to the west at that time (Banks and Driver, 1957). The fault is thought to be related to older, deeper faults (Jurassic normal faults at the eastern margin of the Espino Graben). These may explain why the area is characterized by abnormally high temperature gradients (3.6 - 4.5°C/100m: Funkhouser *et al.*, 1948).

There are no seeps in the Greater Anaco Area (Fig. 2). Reservoirs are provided by up to 70 separate sandstone intervals in the Merecure and Oficina Formations, which contain oils of 33-47°API gravity and are gas-rich. In several fields along the trend, Tertiary terrestrially-sourced oil is present in the San Juan, Caratas, Carapita and Oficina Formations. Tertiary sources are thought to be mature in areas west of Anaco. According to Talukdar (1992), Type III source rocks have probably generated the terrestrial oils found in the area. The presence of Tertiary source rocks in the area was noted by James (2000), but it is also interesting to speculate on a change of organic facies in the Querecual Formation, similar to that seen in the proximal facies of the La Luna Formation, in the Barinas-Apure Basin.

## The Maturín Sub-basin

Abundant oil and gas seeps occur along the eastern part of the mountain front that forms the northern limit to this area (Fig. 3b). The world's largest asphalt lake occurs at *Guanoco* and covers 1,100 acres (Halse, 1932, quoting Carver, 1887; Gonzalez de Juana *et al.*, 1980) (Fig. 2), and there are further asphalt lakes in the same area at *La Breal* and *Lago Saldado*. Oil and gas seeps also occur near the crest of a large, linear clay diapir, part of a system that extends to Trinidad, at *Pedernales* (*see below*), where asphalt was extracted in the late 1800s. No seeps occur in the south in the area of the Orinoco Heavy Oil Belt.

At the *Guanoco* field (discovered in 1913) oil was produced from fractures in the San Antonio Formation. The *Quiriquire* (1928) and *Jusepín* (1938) fields were shallow discoveries in Pliocene (plus some Oligocene) and Miocene sandstones in stratigraphic and anticlinal traps which are more structured at deeper levels (Figs. 2 and 6b). The *Pedernales* field (1933) is located near mud volcanoes, oil and gas seeps and an asphalt lake. Oil is stratigraphically trapped in Mio-Pliocene sandstones of the La Pica Formation, adjacent to a large Pliocene diapir of Miocene Carapita Formation shales (Fig.6c).

Drilling much further to the south discovered the stratigraphically-trapped Heavy Oil Belt in 1935 (*see below*). North of this, the *Temblador* field (discovered in 1935; illustrated by the *Tucupita* field (1945) (Figs. 2 and 6d) produces from Miocene Oficina Formation sandstones (35% porosity) sealed by southward-hading normal faults.

The *Oficina* field (discovered in 1937), originally defined by gravity measurements as an anticlinal structure, was the first Venezuelan field to be discovered using seismic methods. Trapping here involves a conjugate system of normal faults that throw basin- and cratonwards. Around thirty other accumulations were subsequently found in the Greater Oficina Area. Multiple sandstones in the Oficina Formation were deposited as fluvial/deltaic channel sand bodies. Porosities are 10-30% and permeabilities 50-1,000mD. The sandstones are 1-30m thick, and up to 70 are present. Most of the oil accumulations have gas caps. *Oficina* oils generally are heavier in the deeper and sandier parts of the formation and there is a general southwards decrease of gravity (Talukdar, 1992). Strong mixing of Cretaceous and Tertiary sourced oils is indicated by the presence of waxy crudes and high GORs. Rabasso-Vidal

(1985) noted that most of the sand bodies are channel deposits, elongated north-south. Coastal or littoral bodies would be oriented E-W and should offer stratigraphic trapping opportunities. Similarly, Funes and Itriago (1994) studied fields in the Oficina and Anaco areas, and estimated that 13% of reserves are stratigraphically trapped, suggesting that significant reserves remain to be discovered in similar traps in the area.

The deeper, Furrial (or Greater Furrial) trend (discovered in 1986) is a series of large, *en échelon* anticlines associated with blind thrusts (Figs. 2, 3b and 6e). Long oil columns occur in Oligocene (Naricual Formation), and Cretaceous (San Juan Formation) sandstones (Carnevali, 1988; Aymard *et al.*, 1990; Prieto and Valdes, 1992). Most production comes from the Naricual Formation. Rodriguez (1995) reported volumes of 16.4 B bbl of oil and 50.5 TCF gas in place. No oil-water contact has been found and the down-dip limit of oil appears to be tar. Tear faults (lateral ramps to the thrust sheets) provide lateral seals and subdivide the 100-km long Furrial trend. Different oil gravities are present in the separate structures, so that *Tejero* oil is lighter than *Carito* oil. Yet lighter fractions are predicted for structures such as *Casupal-Mata Grande* and *Tonoro*, located further west (Garcia, 1992). The structures, fault propagation anticlines, are known to extend below the Pirital Fault, especially in the west (Lander, *et al.*, 1993). Fields on this trend are *Carito* (discovered in 1988), *Tejero* (1988), beneath the *Santa Barbara* gasfield, and *Boquerón* (1989).

In 1990, the well *Amarilis-1* tested a deeper structural play basinward of the Furrial trend (Figs. 2, 3b and 6). It found hydrocarbons in turbidite sandstones (Barrios and Sams, 1992) within the Miocene Carapita Formation (the regional seal to the Oligocene and Cretaceous accumulations). Sams *et al.* (1992) discussed two possible settings for this accumulation: its seismic structure could be interpreted as either as a thrust-related anticline or as a fan within the syncline.

In early-1994, the discovery of a new province in the east of the Maturín sub-basin was announced. A 300-km long, E-W trend of gently inverted structures, known as Las Piedritas/Acema Casma, shows that Andean contraction has penetrated deeply into the foreland (Fig. 3b). The structures occur in association with shallow gravity faulting that trends N-S to E-W, downfaulting to the east (Daza and Prieto, 1990). Oil occurs in lower Miocene, transgressive sands sealed by middle Miocene, deep marine shales (Barrios and Iusco, 1997). The sands, at around 4,500 m depth, have 61 m mean thickness, and porosities and permeabilities ranging from 12 -15% and from 50-1,000 mD, respectively.

Recent, deeper drilling in the *Quiriquire* area (*Tropical-1*) has realized significant production from reservoirs in the Cretaceous San Antonio and San Juan Formations.

### The Orinoco Heavy Oil Belt

Reservoirs in the Orinoco Heavy Oil Belt (discovered in 1935) are dominated by stratigraphic trapping provided by the onlap of sands, onto basement on a north-dipping monocline, and by heavy oil plugs (Fig. 3b). The belt, 460-km long and up to 40-km wide, includes six main producing areas (*Machete, Zuata, San Diego, Pao, Hamaca and Cerro Negro*; Martinez, 1987); however, convention currently refers to the four areas shown in Fig. 2. Most of the oil is trapped in fine to very coarse, unconsolidated Miocene Oficina sands in the *Zuata, Hamaca* and *Cerro Negro* areas of the Maturín Sub-basin and in the Oligocene-lower Miocene La Pascua, Roblecito and Chaguaramas sands (equivalents to the Oficina Formation) in the *Machete* area of the Guárico sub-basin. In the latter area, oil also occurs in the massive, unconsolidated sands of the Albian-Coniacian Canoa Formation (Kiser, 1987).

Although the oil occurs at shallow levels (less than 610 m to more than 1,220 m (Isea, 1987), there are no surface indications. Zamora *et al.* (1988) suggested that the belt may extend below the poorly-explored, swampy, southern part of the Orinoco delta, where a further 25 to 226 x 10<sup>9</sup> bbl of oil-in-place may be trapped.



The oil was derived from the Upper Cretaceous Querecual Formation (Cassani *et al.*, 1988). According to Chigne *et al.*, (1993, 1995) earliest generation occurred in the northern part of the area during the Late Eocene and Early Oligocene. Most of the oil migrated 150 km up the then-undeformed southern flank to the Heavy Oil Belt; oil formed in younger, Early Miocene to Recent, southward-migrating kitchens became trapped against faults north of the Belt. Early, long-distance migration occurred along regional carrier beds and unconformities. This occurred within the Upper Cretaceous San Juan Sandstones, along and across unconformities to the Eocene Los Jabillos Formation, stepping up to the basal, Oligo-Miocene Merecure-Oficina sandstones above Oligocene and Miocene unconformities and finally to the Oficina Formation pinchout (Talukdar *et al.*, 1987). George and Socas (1994), however, alternatively suggested that the Heavy Oil Belt kitchen area lay in the vicinity of Paria/Trinidad.

The oil contains 4% sulphur and significant amounts of vanadium and nickel. Bitumen (4°API) is also present. Despite high densities, the oils are highly mobile in the reservoir where temperatures range from 50°C at 800m to 60°C at 1,100m. Natural gas also occurs in the belt, in the western, (Gorin, Machete and San Diego) areas. This is thought to have accumulated independently from the oil (Martinez, 1987).

An excellent history of the Belt was provided by Martinez (*op cit.*). The first well drilled in the belt was *La Canoá No. 1*, in 1935. It was abandoned at 1,176m after testing 40 b/d oil (7°API) in tar sands in a thin conglomeratic zone on top of basement. In the next 30 years, 58 wells were drilled. Fifty of these encountered heavy, viscous and unmarketable oil in the lowermost sands of the Miocene Oficina Formation. Most were abandoned without testing. At this time the area was called the "Tar Belt". In 1978, areas of the belt were assigned to four PDVSA (Petroleos de Venezuela) filial Venezuelan companies and in the five-year period 1979-1983, 669 wells were drilled and 15,000km of vibroseis lines were recorded, along with a 54,000 sq. km airborne magnetometer survey. The effort included recording 5.5 km of logs and 4,500m of coring.

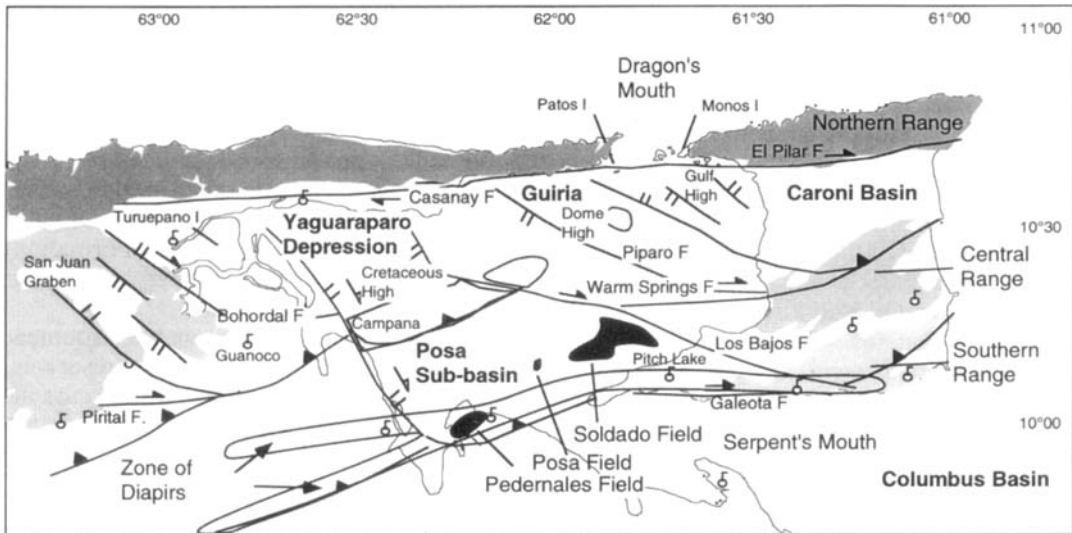
Following re-entry of international companies into Venezuela, this reserve base has attracted a great deal of attention. Several multi-billion dollar schemes are in place to transport and upgrade the heavy crude, in partnership with Venezuelan affiliates.

## Gulf of Paria

This marine area is confined by the Orinoco Delta to the west and by Trinidad to the east (Fig. 7). To the NW and NE lie the metamorphic rocks of the Paria Peninsula of eastern Venezuela and the Northern Range of Trinidad. The Isla de Patos (Venezuela) and the Chatachapos, Huevos and Monos Islands (Trinidad) show the continuity of these elements across the Dragon's Mouth channel, which is the Gulf's northern outlet to the Caribbean Sea. Trinidad's Central Range correlates structurally with the front of the Interior Range of eastern Venezuela and indicates a similar, but offset, link across the Gulf. Likewise, Trinidad's Southern Range is a continuation of a shale diapir zone that extends from Tonoro-El Lirial SW of the town of Maturín, via Joyo, Guanipa and Pedernales and thence via southern Trinidad to the edge of the continental platform east of Trinidad. Oil and gas seeps and asphalt lakes characterize this zone. To the SE the Gulf opens to the Columbus Basin, via the Serpent's Mouth channel.

Perez de Mejía and Tarache (1985) noted that neither gravity nor magnetic data allow basement depth below the Gulf to be determined. Extrapolation of onshore trends indicates deepening to around 12,000 m. According to Erlich and Barrett (1990) Bouguer gravity suggests a crustal depth of 10-14 km below the Amacuro/Gulf of Paria boundary to the south.

Significant seeps and fields surround the Gulf. Two of the world's largest asphalt lakes occur at *Guanoco* (1,100 acres) in Venezuela, and at *Pitch Lake* in Trinidad (150 acres). Oil with a shallow carbonate/evaporite signature has been identified in Pedernales and offshore eastern Trinidad (*Poui* field). It may be related to Lower Cretaceous evaporites penetrated in the Gulf of Paria (Couva evaporites: Bray and Eva, 1983).



**Fig. 7. Structural elements of the Gulf of Paria pull-apart basin (see location in Fig. 1). Metamorphic rocks in the Paria Peninsula continue in the Northern Range of Trinidad. Cretaceous rocks of the Interior Range of Venezuela (Fig. 1) continue beneath thin cover in the north, but lie deeply buried beneath in the south. The thrust front of the Interior Range in Venezuela corresponds to the Central Range of Trinidad. The Southern Range of Trinidad is the eastward continuation of a diapiric trend that begins in the Maturin Basin.**

Structurally, the Gulf of Paria is poorly known. It could be interpreted as a pull-apart basin formed where east-west trending dextral faults associated with the Caribbean—South America plate boundary step south to the Galeota Fault, south of Trinidad. It is an eastward continuation of Eastern Venezuela, with significant normal faulting superimposed since the Miocene. The Casanay-El Pilar Fault system and the diapiric zone limit the area to the north and south, respectively. The intervening area is crossed by SE-trending dextral faults such as the Bohordal, Los Bajos, Warm Springs and Piparo faults. These are synthetic to the regional east-west faults and also have significant normal displacements. The buried thrust front of the Interior Range is offset along these faults below the Gulf and then resurfaces in Trinidad's Central Range. This front separates the northern Guiria area from the southern Posa sub-basin. The Cretaceous section of the Interior Range occurs below upper Miocene or younger rocks in the north, while a more complete and very thick Cretaceous – Neogene section occurs in the south. The deepest wells have reached the Oligocene in the south (ca. 4,000 m) and the Cretaceous in the north (ca. 3,600 m).

The Guiria sub-basin comprises a central high flanked by the Yaguaraparo Depression to the west and the Caroní Basin to the east (Fig. 7). The Yaguaraparo Depression continues onshore south of the Paria Peninsula. There are no well data here. Geophysical data indicate

3,600m of Tertiary sediments in a syncline in the vicinity of Turuépano Island. A zone of "Cretaceous Highs" crosses the Gulf from the Campana area in the SW, through the Plata High, the Posa-40 High, to the Domoil High. The highs were covered by Tertiary sediments in the south, but remained positive in the north. Drilling on them has been unsuccessful. In the Guiria sub-basin Upper Miocene or younger sediments lie above the Cretaceous rocks. The latter include significant, Lower Cretaceous anhydrite deposits, mentioned above, that may correlate with the Cariaquito Formation of the Paria Peninsula and the Laventille Formation of Trinidad's Northern Range.

The Posa sub-basin is located between the Los Bajos fault, the zone of Cretaceous highs and the Diapiric Zone. Numerous intraformational unconformities, thrusts and growth faults result in poor seismic continuity and difficulty in correlation, especially from north to south and where no well data exist. In addition, lateral displacement has juxtaposed blocks of disparate origins. Thus, the Posa sub-basin has a composite sedimentary column comprising the Upper Cretaceous Guayuta Group, the Upper Cretaceous-Eocene Vidoño and Caratas Formations, the Miocene Carapita, Tamana-Lengua and La Pica Formations, and the Plio-Pleistocene Las Piedras and Paria Formations. Two fields have been discovered in this area and a further discovery in this area was made in 1998 by the well *Corocoro-1*, north of the *Pedernales*. The *Soldado* field (Fig. 6f) is an anticlinal feature associated with the Los Bajos Fault, while the *Posa* is situated on the northern flank of the regional Guanipa Syncline. Source/oil geochemical correlation suggests a Cretaceous source for these oils. A low thermal gradient (1.8-2.7°C/100 m) is reflected by low VR values measured in *Soldado* wells (Ro 0.8 at 4,300m). The onset of oil generation occurred in the late Oligocene to Pliocene and peaked from the late Miocene onwards.

The shallow-marine to deltaic, lower Pliocene Manzanilla Formation provides the most important reservoirs of the *Soldado North* field. This unit extends into the gulf as far as the international border, where it interfingers with the La Pica Formation. Source areas for these deltaic sands were units such as the Northern and Central Ranges of Trinidad. The *Soldado Main* field produces from the Miocene Cruse Members, part of the same northerly-derived deltaic system. These late Miocene deltaic deposits (the Cruse, Forest and Morne L'Enfer Formations) form important reservoirs in southern Trinidad. Stainforth (1978) suggested that these sands were delivered by the proto Essequibo River in the Guayana area (palaeocurrent analysis indicates a SE source). Mio-Pliocene sands are notoriously unclean in this region and permeabilities are low. In the *Posa* field, for example, porosities are around 33%, but permeabilities range from 50 to 250 mD.

Deeper tests in this area have recovered 27-34° oil from thin sandstones in the Naparima Hill Formation (10-25% porosity) and heavy 12° oil from the overlying Nariva Sandstone.

## BARINAS-APURE BASIN

This is the least explored and least prolific of Venezuela's main hydrocarbon provinces (632 MM brls produced)(Fig. 1). A few seeps occur within the Mérida Andes (Fig. 3c). Jordan (1984) noted that the flank of the basin has abundant surface hydrocarbon indications in Cretaceous strata and that important seeps and asphalt impregnations occur at the Cretaceous-Upper Tertiary unconformity outcrop in the Río Quiú de Barinas and at Mina de Cope in Táchira State.

### Geological occurrence of oil- and gasfields

The basin is asymmetric and deepens to the NW from the Guayana Shield towards the foredeeps (up to 9,000 m in the SW) along the SE flank of the Venezuelan Andes (Fig. 3c). It is limited to the north by the NW-trending El Baúl Uplift or Arch. In the NW, this high trends

westwards and is known as the Alto de Guanarito. In the south, the Arauca Arch (Santa Barbara High of Young, 1988) separates the basin from the Colombian Llanos Basin (also referred to in Venezuela as the Apure Basin: Loaiza *et al.*, 1990). The Mérida Arch divides the basin into a northern area, known as the Northeast Monocline, and the southern, Capitanejo Basin, also known as the Barinas Deep. Thinning of the Upper Cretaceous section, with increased terrestrial content in the source intervals, and the absence of the Palaeocene show that the arches were positive at these times. The Jurassic San Fernando Graben in the SE subsurface (James, 2000, Fig. 9) trends NE towards, and possibly links with, the Espino Graben of the Eastern Venezuela Basin. The Nutria Graben splays NNE from the San Fernando Graben.

Structural analysis based upon aeromagnetic data, calibrated by seismic and well data (Young, 1988) has defined numerous structural elements parallel to the adjacent Mérida Andes (e.g. the Caño Limon – Guafita Fault system), to which they are probably related. Chigne and Hernandez (1990) likewise noted that NE-SW faults (parallel to the Andes) are common, extending for 40-80 km and involving reverse displacement (probably dextral transpression). In addition, there are important east-west trending structures in the north and centre of the area, which, according to this paper, can be related to the plate boundary further north. Portilla (1993) observed that the structures are either pre-Oligocene or Mio-Pleistocene. Only the former constitute important traps for oil. According to Talukdar (1992), the structures in the Barinas fields (faults and folds) formed in the Late Cretaceous-Palaeocene and were reactivated in the late Eocene.

Structures adjacent to the Andes in the SW of the basin include basement-involved thrusts that die out in the Oligocene section and are commonly associated with gentle, small-scale anticlines. The thrusts are west-vergent and contrast with the general Andean outward vergence (Audemard, 1991). Further north, thrusts verge to the SE (Urbina and Cornelio, 1993). The NW Barinas-Apure Basin became separated from the Maracaibo Basin during Late Neogene uplift of the Andes. Earlier sections in the two basins are correlative.

The Barinas fields (Figs. 2, 3c and 8), such as *Silvan* (discovered in 1949), *Silvestre* (1948), *Sinco* (1953), *Maporal* (1957), *Palmita* (1957), *Hato* (1961), *Paez-Mingo* (1965), and *Caípe* (1967) lie on the northern flank of the Mérida Arch and are traditionally ascribed to anticlinal and fault trapping, the latter being more important. The structures have low relief. Their location above the hinge line of the basin suggests that normal faults may play the same trapping role as they do in the *Las Mercedes* and *Oficina* fields of the Eastern Venezuela Basin. Basal Tertiary (Eocene Gobernador Formation) and highly porous and permeable sandstone belonging to the Upper Cretaceous Escandalosa Formation provide the reservoirs. These fields are all small except *Silvestre* and *Sinco* (155 and 320 MM bbl, respectively). Oil gravity is 22-25° API. The Barinas field oils occur in the Cretaceous Escandalosa Formation sandstone and in the Eocene Gobernador Formation sandstone. Porosities range from 20-28%, and permeabilities are in the order of 200-2000 mD. The Eocene Pagüey Shale provides an excellent seal. Oligocene upper Carbonera shales seal the *Caño Limon* field (Cleveland and Molina, 1990). Lopez *et al.*, (1998) reported that *La Victoria* and *Guafita* oils are paraffinic-naphthenic, derived from a siliciclastic source, while the *Caípe*, *Silvestre*, *Sinco*, *Silvan* and *Palmita* oils are aromatic-naphthenic, from a calcareous source. Both are Cretaceous-sourced, from different facies of the Navay Formation. Biomarker studies indicate less mature oil in *La Victoria*, more mature in *Caño Limon* and *Arauca*, suggesting two phases of migration: first at 25-20 Ma (*La Victoria*), then around 15 -10 Ma to *Caño Limon* and *Arauca* (120 km of migration: Chigne *et al.*, 1997).

The *Guafita* (26-30° API) and *La Victoria* (30-36°) fields were discovered in 1984 (Figs. 2 and 8). *La Victoria* contains 400 MM bbl in place. The structure is either not filled to spill or spills along the fault to the east. *Guafita* had 1 B bbl oil originally in place. Like the *Caño Limon* field with which it associated, it is anomalously large compared to other fields in the basin. The structure is associated with a Jurassic graben. Other wells drilled along the *Caño Limon - Guafita* trend (*Guasqualito-1x*, *Amparo-1x* and *Caño Muñoz*) were dry.

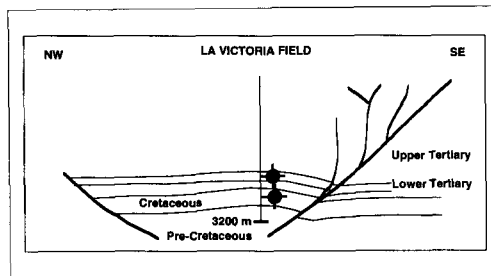


Fig. 8a. La Victoria field (from Chigne and Hernandez, 1990).

**Trap:** Two anticlines bounded by reverse, strike-slip faults to the east.

**Reservoir/seal:** Palaeogene (17%) and Cretaceous (13-27%) sandstones, sealed by overlying shales.

**Source/kitchen:** Cretaceous Quevedo, Escandalosa and La Morita Fm (La Luna Fm equivalents), in South Andean Foredeep.

**Hydrocarbons:** 400 MM brl STOIIIP, 33° API oil, not full to spill.

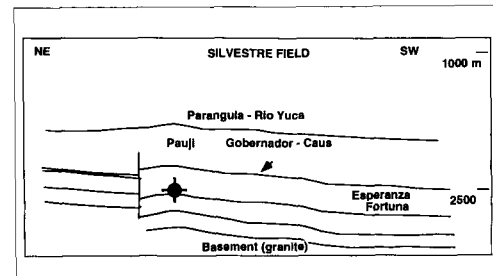


Fig. 8b. Silvestre field (after Christensen, in Smith, 1962).

**Trap:** Fault blocks on NW-plunging arch.

**Reservoir/seal:** Mostly Cretaceous Fortuna sandstones and limestones, 25% porosity.

**Source/kitchen:** La Luna equivalent in foredeep adjacent to Mérida Andes, several models in literature.

**Hydrocarbons:** 24-28° API, 200 MM brl reserves.

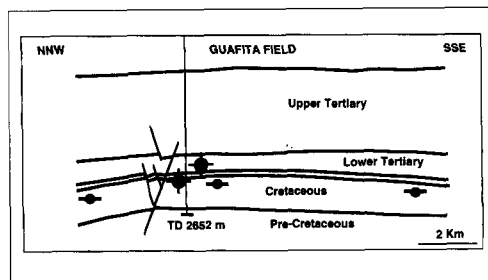


Fig. 8c. Guafita field (after Chigne and Hernandez, 1990, 1993).

**Trap:** Anticline associated with dextral Cano Limon Fault.

**Reservoir/seal:** Oligocene ("Guafita") basal, deltaic sandstones (26%) and upper Cretaceous Navay Group Quevedo Member.

**Source/kitchen:** Upper Cretaceous Quevedo, La Morita and Escandalosa Fms. (La Luna Fm equivalents), mature in the Capitanejo Trough adjacent to the Mérida Andes.

**Hydrocarbons:** 1 billion brl in place, 250 MM brl recoverable (possibly 40%), 29° API oil.

Chigne and Hernandez (1990) described reservoirs in basal Tertiary and Upper Cretaceous sandstones. In the *Guafita* field oil occurs in lower basal Oligocene sands (in the north block) and in all basal Oligocene sands plus Cretaceous upper Navay Group (in the south block). The basal Guafita sands are lower delta-plain deposits, coarse-grained, poorly sorted and poorly consolidated, with 26% primary porosity, and 1,000-9,000 mD permeability. *La Victoria* oil occurs in basal Tertiary sandstones (17% porosity, 700-3,100 mD) and in the Upper Cretaceous (the main reservoir consists of calcareous and glauconitic sandstones with thin interbedded limestone).

From the foregoing discussion, it is clear that migration has occurred laterally, sometimes over long distances, to structural and stratigraphic traps on the foreland ramp, and vertically to fold and thrust-related, structural and stratigraphic traps in the sub-Andean zones.

## OFFSHORE

Offshore activity has been significantly lower than that onshore, partly because of the early and highly successful developments which have taken place onshore, and partly because the offshore seemingly offers only locally developed, generally poor quality Tertiary source rocks and reservoirs. The most significant discoveries to date involve several TCF methane accumulations in the Carupano Basin, in the NE.

### The Netherlands and Venezuelan Antilles

Three wells have been drilled to test a half graben adjacent to Aruba (Fig. 1), penetrating mainly shales of ?late Eocene, Oligocene to Recent age which rest upon a mixture of metamorphic and igneous rocks and red claystones (Curet, 1992). The sedimentary section records rapid subsidence to abyssal depths, followed by shallowing to present-day depths. This area seems to lack both source and reservoir rocks. No other drilling in the vicinity of these islands has been reported.

### Gulf of Venezuela

The Gulf is a pull-apart basin bounded by the Guajira and Paraguaná peninsulas to the west and east and by the Falcón/Maracaibo Basin area to the south (Fig. 1). It opens northwards to the Caribbean Sea.

Although seismic surveys have been performed here, the area remains untested by the drill. Magnetic data indicate shallow basement in the west (see Bonini, 1984, Fig. 1). Viable La Luna Formation source rocks occur in the southern part of the adjacent Guajira Peninsula (Renz, 1960, 1982). In the east, the Oligo-Miocene Urumaco Trough on the western side of the Paraguaná Peninsula is closely similar to La Vela Bay on the east, although it lacks a basement high. The presence of a working hydrocarbon system is evidenced by the onshore, updip *El Mamón* field. The lower Miocene Agua Clara Formation source rock may be thick in this area. According to Macellari (1995), Eocene subsidence occurred in the western part of the Gulf of Venezuela and Oligo-Miocene subsidence occurred in the Urumaco Trough and La Vela Bay.

### La Vela Bay

La Vela Bay lies to the east of the Paraguaná Peninsula (Fig. 1). It is a pull-apart basin with local Eocene or Oligocene red beds and a mainly Miocene-Recent fill. The basin dips to the SW in the west, and to the SE in the east; up to 4,500 m of sediments are present. The E-W trending Adicora Fault limits the area to the north. The Los Médanos Fault forms the western

limit of the basin (the eastern margin of the Paraguaná Peninsula) and the La Vela Fault forms the southern limit. The basin is crossed by a system of NW-SE faults that define a basement high known as the Pilar Tectonico. The fractured basement of this high (phyllites and gneisses—metamorphosed during the Cretaceous) and overlying carbonates and sandstones provide reservoirs for the light oil and gas in the area. Source rocks are considered to be present within the Oligocene Guarabal and Agua Clara Formations. Thirteen wells have been drilled in this area, resulting in five discoveries. However, there has not yet been commercial production from this area.

### **Cariaco Basin (Tuy-Cariaco Basin, Gulf of Barcelona, Unare Bay)**

The Cariaco Basin (Fig. 1) is a pull-apart formed where the dextral Morón - El Pilar fault system sidesteps to the right (Schubert, 1982). It comprises two sub-basins with water depths up to 1,400m (Schubert, 1985). The basin contains anoxic waters below a 300 m sill and cores have recovered 5 - 11 m of dark greenish-grey organic-rich lutite with preserved foraminifera and pteropods dating from 10,900 years (Heezen *et al.*, 1959).

In the surrounding area, an oil seep on Cubagua Island (a small island between Margarita and the mainland, Fig. 1) was mined in 1912. Small seeps occur in the west of the Margarita Island. Another seep at the extreme western end of the Paria Peninsula was tested by well *Araya-1* in 1912, but the results have been lost.

Blanco and Giraldo (1992) noted that the platform that carries Margarita and La Tortuga Islands and the Cariaco Basin are floored by nappes. In the Cariaco Basin, Upper Cretaceous metamorphic and igneous basement is overlain by local Middle-Upper Eocene, marine conglomerates, limestones and shales (cropping out on Margarita as the Grupo Punta Carnero wildflysch), Oligocene-Lower Miocene fluvial sands and Upper Miocene-Quaternary shales and sands. Eocene and Oligocene marine shales include fair source rocks north of the Tortuga-Margarita high; Eocene and Miocene marines shales include good source rocks to the south.

A twelve-well campaign in the early 1980s resulted in three oil, five thermogenic gas and two condensate discoveries (Talukdar and de Bolivar, 1982), leading to estimates that this basin contains recoverable reserves in the order of 50-157 MM bbl. The oils are derived mainly from marine organic matter, with some terrestrial contribution. There has been no commercial production from this area.

### **Carúpano Basin**

Castro and Mederos (1985) gave a stratigraphic analysis of the Carúpano Basin and Ysaccis (1997) presented a comprehensive study of the NE offshore part of Venezuela. The basement includes Jurassic-Lower Cretaceous metabasalts and the shales, limestones, cherts, radiolarites, volcanoclastics and basalts of the Lower-Upper Cretaceous Mejillones Complex. Extension in the NE occurred in the Eocene - Oligocene. It was followed by inversion in the Oligocene and by further transtension in the Mio-Pliocene. Neritic to bathyal environments accommodated mainly muds until the Pliocene, when a regression allowed progradation of shallow marine sands. These sands contain biogenic methane at the *Mejillones* and *Patao* fields, and condensate at *Rio Caribe* (for which there is no published explanation). Reserves amount to some 6-7 TCF gas. The fields are located on a horst system that continues north of Trinidad, where only biogenic gas is reported.

## **GENERATED—ACCUMULATED VOLUMES**

It is interesting to consider the efficiency of hydrocarbon generation and entrapment in this oil-rich country. Talukdar and Marcano (1994), for example, calculated a Generation-

Accumulation Efficiency (GAE) of 14% for the Maracaibo Basin, putting it at the top (except for one small basin) of 16 basins discussed by Magoon and Valin (1994) (c.f. GAE of 4.95 for the La Luna in Colombia: Pérez-Téllez, 1995).

According to McDowell (1975), data from many basin studies suggest that one-quarter to one-third of oil generated is a practical maximum for the oil trapped, with a more likely average figure of 10% and a range of 1-25%. Magoon and Valin (1994) and Hunt (1995) reported values up to 15% for reservoir oil as a function of generated oil. McDowell (*op cit.*) calculated a 10% efficiency for the Iranian/Arabian Basin.

The known original STOIP of Venezuela was, conservatively, in the order of 1.5 trillion barrels of oil equivalent. This must be increased significantly to account for the volume reduction involved in biodegradation, volatile loss and oxidation that resulted in the formation of heavy crudes in the Orinoco Heavy Oil Belt and the Bolivar Coast Complex. Using a conservative factor of two to account for this shrinkage (i.e.  $2 \times \text{STOIP} = 3$  trillion BOE), a globally reasonable generation/accumulation efficiency of 10% implies the generation of at least 30 trillion barrels in Venezuela. An immature Luna source with parameters quoted by Talukdar and Marcano (1994, mean TOC 5.56 wt.%, mean density 2.65 g/cm<sup>3</sup>, mean net thickness 65m, HI 650 mg/gm) would have to have matured over an area of 800,000km<sup>2</sup> to generate such volumes. The reported oil kitchens (Fig. 9) do not have this capacity. For example, the Talukdar and Marcano (*op. cit.*) estimate of hydrocarbons formed in the Maracaibo Eocene and Miocene-Recent kitchens amounts to some 1.8 trillion barrels.

Possible explanations for these larger reserves include the presence of additional source rocks, thicker net source rock values, wider source areas/larger kitchens, additional phases of generation, additional reservoirs/traps and remigration of oil from older to younger traps.

To account for the 2.7 trillion barrels of heavy oil in the Western Canada sedimentary basin, Garven (1989) considered highly efficient, long-distance transport of miscible and immiscible oil within a gravity-driven, Devonian carbonate aquifer. Whereas Cretaceous source rocks were formerly thought to have sourced the oil, Devonian, Mississippian and Jurassic sources were probably involved as well. The Canadian accumulation occurs updip to the east of the basin in sandstones flanking the Precambrian Shield, to the west lies the Rocky Mountain Fold and Thrust belt. The setting provokes comparison with the Eastern Venezuela Basin.

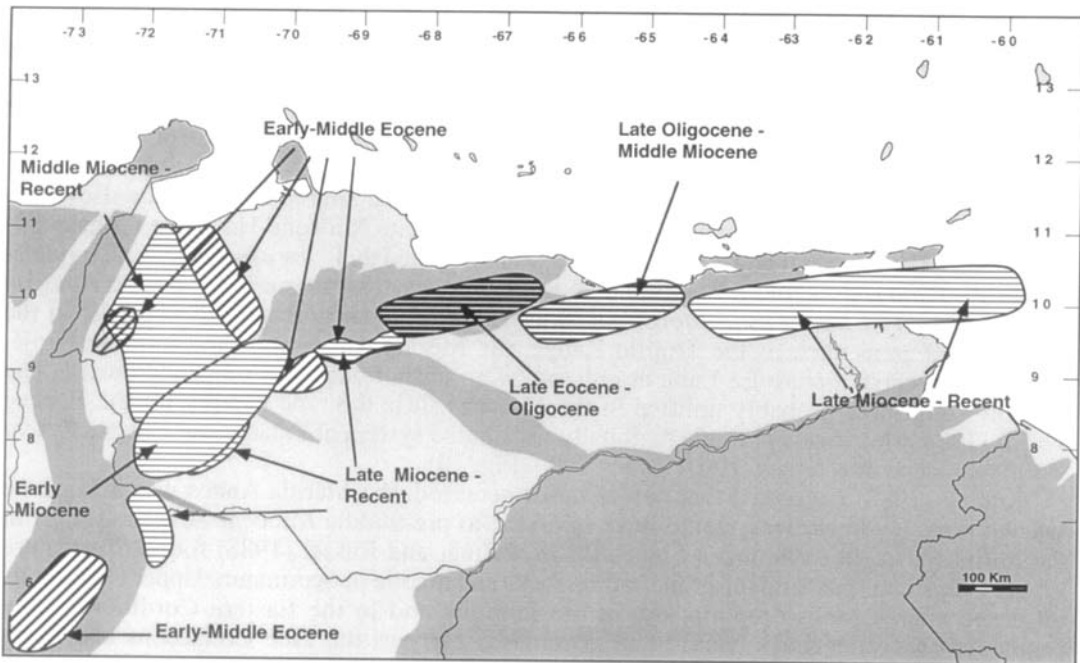
Cassani *et al.*'s (1988) biomarker investigation of crudes from Venezuelan basins indicates that most originated from marine Cretaceous source rocks. However, they also stated that large amounts were biodegraded after accumulation in the reservoir.

The presence of additional source rocks is indicated locally, for example, by the Aptian Machiques Member in the western Maracaibo Basin. Some areas of Jurassic rifting, like the Machiques Trough (James 2000, Fig. 9), continued to undergo rapid subsidence in the Cretaceous and accommodated local source rocks. Llerena and Marcano (1997) considered that both this member and the overlying La Luna Formation entered the oil window as early as the Campanian/Maastrichtian in the northern part of the Colón district (SW Maracaibo Basin). Oils migrated east and SE towards developing structures.

Bockmeulen *et al.* (1983) proposed that Eocene generation occurred in the area NE of the present-day Maracaibo Basin. They speculated that deep marine, Eocene shales in the Falcón and Lara areas were source rocks. Oil from this deep would have been trapped in (Misoa) sandstones in the south/central part of the Maracaibo area. The oil would have remigrated, during Guarao subsidence, along an Oligocene unconformity to traps such as the Bolivar Coastal field. These authors estimated that the complex could contain up to 200 B brl of oil and noted that while the La Luna was widely believed to be the source, it would have needed to be mature over "an extremely large area" to generate these volumes. They gave no estimate of this, but instead illustrated areas involving a 1,000-m thick shale source, presumably their postulated deep marine Eocene source

It is known today that Tertiary-sourced oils in the Maracaibo Basin are restricted to the SW of the basin (Talukdar and Marcano, 1994). Blaser and White (1984) reported that the Eocene





**Fig. 9. Compilation of kitchen areas reported in the literature for Upper Cretaceous source rocks (La Luna and Querecual Fms). These limited areas, the earliest of which developed in the Eocene, are not sufficient to have supplied Venezuela's huge petroleum resources, which amount to around 1.5 trillion bbl oil.**

section in the known Maracaibo Basin does not contain oil-prone source material. Marine facies of the lower Eocene contains multiple and locally very thick intervals of organic-rich rocks. The total volume of organic matter is probably larger than that of the La Luna, but it consists of hydrogen-poor land-plant debris and is gas prone. They presented geochemical correlations supporting earlier works (Aldershoff, 1953; Gransch and Eisma, 1966) which concluded that oil came from La Luna Formation source rocks. These generated oil and reached gas maturity by the end of the Eocene in the NE area of subsidence. However, while their illustrations show thick Eocene sedimentation extending into western Falcón, the area where maturity occurred appears only as a narrow zone along the NE coast of Lake Maracaibo (their Figures 12 and 18).

In eastern Venezuela, George and Socas (1994) discussed the possibility that the thick, Late Oligocene—Middle Miocene pro-delta Carapita shales may contain source horizons that are mature over large areas. Tocco *et al.* (1994) provided data to support this idea, reporting organic matter in two zones within the Carapita Formation. Oil recovered from well *Amarillis-1x* is derived from a land plant source and correlates with the Carapita source material, thought to have matured in the Late Miocene. However, there is little indication of Tertiary sourcing east of western Oficina.

Krause and James (1990), James (1990) and James and Rigby (1993) emphasized that the present-day basins of Venezuela are mere remnants of a much larger hydrocarbon province in terms of the original regional and diachronous distribution of Cretaceous source rocks. Generation before the Guarao Orogeny (which commenced in the Early Oligocene) would

have involved much larger kitchen areas than most models consider. This differs from the belief of Talukdar *et al.* (1985) that the Maracaibo Basin is an example of a basin in which all the hydrocarbons present were derived from source rocks within the area of the basin. It contrasts with the statement of Cassani *et al.* (1988) that maturation of Cretaceous source rocks occurred mainly during Miocene-Recent subsidence, with the one exception being the NE area of the Maracaibo Basin.

According to Talukdar and Marcano (*op. cit.*), La Luna source rocks matured over an Eocene ("phase I") generation area of 15,000 km<sup>2</sup> and a late Miocene-Holocene ("phase II") area of 32,500 km<sup>2</sup>, a total of 47,500 km<sup>2</sup>. These authors noted that "*the areal extent of thermally mature La Luna source rock for phase I at the end of Eocene time was restricted to an elongate area southwest of the Trujillo Range*". However, the Maracaibo Basin did not exist in the Eocene, and areas such as the Trujillo Range, the Mérida Andes and the Sierra de Perijá, which today carry mature La Luna at outcrop, were unshortened and remained buried. The Trujillo Range was probably uplifted in the Miocene. It is the type locality for the Eocene Trujillo Formation that is part of a regionally distributed system of Palaeocene-Eocene flysch/wildflysch deposits (James, 1997; James 2000, Fig. 10).

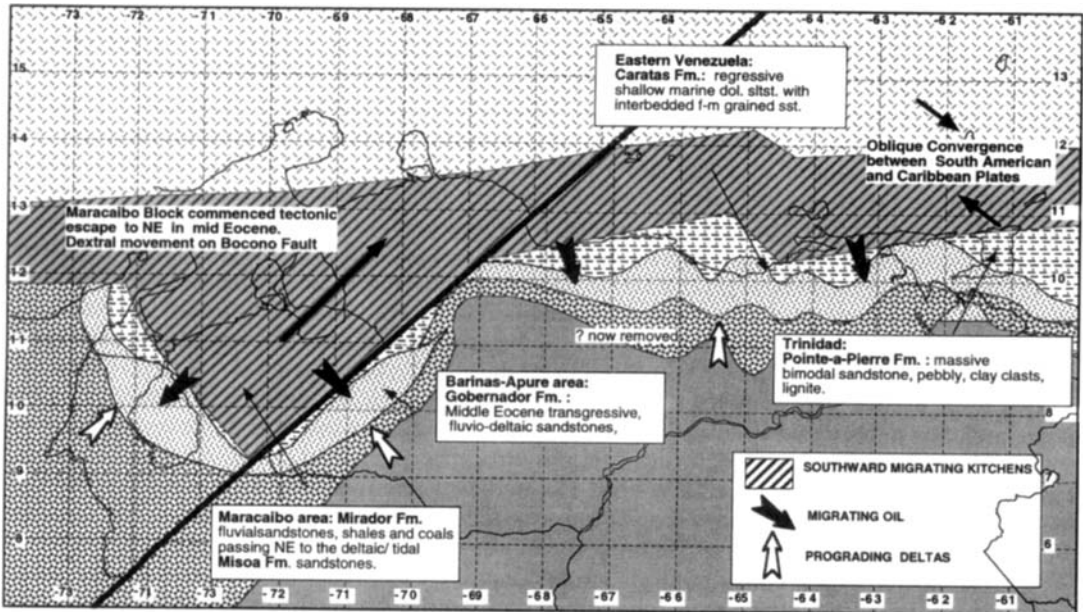
Findlay (1988) suggested that before uplift occurred, the Mérida Andes was a Miocene kitchen area. Hydrocarbons would have migrated to pre-middle Miocene structural traps in the Barinas area. In Colombia's Llanos Basin, Palmer and Russel (1988) found overmature Lower Cretaceous gas- and oil-prone source rocks and mature to overmature Upper Cretaceous oil-prone source rocks cropping out in the foothills and in the Eastern Cordillera. They concluded that such rocks could have matured as early as the Late Cretaceous and Early Tertiary.

Several studies recognize early Guarao phases of oil generation from source rocks now uplifted in the Interior Range of Eastern Venezuela (Talukdar *et al.*, 1987— middle Miocene; Chigne *et al.*, 1993 — late Eocene and early Oligocene; Gallango and Parnaud, 1993 — early Tertiary; George and Socas, 1994 — pre middle Miocene).

Additional reservoirs are indicated by Rodríguez *et al.* (1997) who identified the potential to find some 2.5 B bbl of oil in deeper, Eocene reservoirs below the traditional fields of the Bolívar Coast Complex. Structural and stratigraphic traps involving fault-controlled sediments and possible deepwater fan sands could have received an Eocene and later hydrocarbon charge, preserving the reservoirs' poroperm characteristics. Martínez (1996) also lent support to the possible presence of deeper, older reservoirs. A sedimentary wedge, of suggested Oligocene age, is apparent on seismic profiles in the north of the Maturín sub-basin. It is overlain by Carapita shales in the north and by the transgressive shales of the Oficina Formation further south. This wedge could involve important stratigraphic traps.

The possibility of earlier traps supplying oil for remigration was indicated by Daal and Lander (1993), who noted that the Oligocene sand reservoirs of the *Yucal Placer* gasfield thicken to the north where black, residual oil occurs in tight reservoirs. Oil protected updip sands from cementation before being displaced by gas. Gallango and Parnaud (1993) suggested that early oil migrated to the El Cantil and Barranquín Formations.

In Eastern Venezuela, site of the world's largest oilfield, the Late Cretaceous – Middle Eocene Caribbean-Guajiro phase of generation was followed by the Oligocene–Miocene–Recent Guarao Orogeny. In both phases, the existing basin would have received charge from a southward-rolling systems of foredeep kitchens related to advancing fold-and-thrust belts. It is feasible that the older phase charged large trap systems, analogous to the Oficina Complex and the Heavy Oil Belt and involving Eocene sandstones, north of the present-day basin. Such traps may have yielded very large quantities of oil for remigration during later deformation. Some accumulations may remain deeply buried, transformed to gas, condensate and pyrobitumens in the manner discussed by Blanc and Connan (1994). Such hydrocarbons occur in the Oligocene-Miocene Los Jabillos and Naricual sandstones of the Furiel complex (*pers.*



**Fig. 10. Palaeogeographic reconstruction for the Early-Middle Eocene. The Mirador and Misoa Formation sandstones form important, quartz-rich reservoirs in the west, in Colombia's Llanos Basin (Fig. 1) and in the Maracaibo Basin. Rivers draining north from the Guayana Shield must also have deposited large quantities of sands in the east. Oil generated during Late Cretaceous — Eocene orogeny could have been housed in such reservoirs.**

*comm.*, Chevalier, 1998). Close by, shallow fields of the fold-and-thrust belt contain oil in the Eocene Caratas Formation and in fractured carbonates of the Cretaceous El Cantil Formation.

A notable contrast between western and eastern Venezuela is the importance of Eocene sandstone reservoirs in the former area and their virtual (and unremarked) absence from the latter area. There are indications that high quality, quartzose Eocene sands were widely distributed. They are known from the Talara Basin in Peru, from the Llanos and Magdalena Basins of Colombia, from the Maracaibo Basin of Venezuela and from Barbados. Eocene sands are postulated to form a large fan in the Venezuela Basin (Driscoll *et al.*, 1995). They were derived from the Proterozoic Roraima Group of the Guayana Shield through erosion that was probably triggered by regional tectonic uplift. A palaeo-Orinoco/Magdalena River draining the Shield deposited the sandstones of the Mirador/Misoya Formation of the west. In eastern Venezuela, just as rivers flowing north from the shield deposited the important sands of the Heavy Oil Belt and the Oficina Complex during the Miocene, they must have transported sands during the Eocene. Large reservoir systems of this age must have existed. These may have disappeared during late Eocene or younger erosion. Alternatively, they still exist below the mountains north of the Eastern Venezuela Basin.

Similar, regional sand-rich systems are likely to have formed during the Oligocene. These may still contain hydrocarbons downdip from the prolific Miocene sandstone reservoirs of the Oficina Complex and the Heavy Oil Belt.

A highly speculative contribution to Venezuela's enormous reserves is suggested by the abundance of graphite in metamorphites of the Northern Ranges. The protoliths of graphitic

marbles and schists probably were bituminous limestones and shales, while graphitic quartzites may have been oil-bearing sandstone reservoirs. The assemblage seems to be a metamorphosed petroleum system, involving Jurassic-Lower Cretaceous source rocks, which generated hydrocarbons during Late Cretaceous – Middle Eocene contraction. It is (remotely?) possible that the system may have supplied some of the country's reserves via intermediate traps.

**To summarize**, source rocks along the northern margin of South America originally had a very large areal extent and were deposited in both Early and Late Cretaceous times and possibly also during the Jurassic. The Eocene sandstones which form important reservoirs in the west probably existed also in the east. At least two major phases of hydrocarbon generation occurred — in the Late Cretaceous-middle Eocene and from the Oligocene to the Recent. The first phase was of regional extent and was accompanied by crustal shortening involving “rolling” kitchens within migrating foredeeps. It could have charged widely-developed structural and stratigraphic complexes. This was repeated in Eastern Venezuela during the Guarao Orogeny. At this time, earlier traps may have released hydrocarbons for remigration. In the Maracaibo Basin area, the latter phase involved the subsidence of early accumulations, the remigration of their hydrocarbons, and the addition of new hydrocarbons formed in the Andean foredeep. The Barinas-Apure Basin may have been isolated from remigrating early-phase oil by the rising Mérida Andes, becoming charged only by local foredeeps formed during the Guarao phase. This basin contains significantly fewer reserves than the Maracaibo and Eastern Venezuela basins. These considerations are addressed by Fig. 10 which depicts a wide areal extent for kitchens involving Cretaceous source rocks and suggests the important development of early-middle Eocene sands in Eastern Venezuela. The latter may survive in the north of the area or they may have been largely eroded.

## THE FUTURE: CONCLUDING REMARKS

The return of international companies to Venezuela has brought additional scientists and technology to investigate the country's geology and to find and develop further hydrocarbon resources. Since many producing fields were discovered some decades ago, revision of their geological characteristics using modern tools will result in improved understanding and enhanced production. Additional reserves will be found within, below and adjacent to the known fields. Directional drilling and enhanced production techniques will allow more oil to be recovered.

Most spectacular is the rapid growth of plans to produce the supergiant Orinoco Heavy Oil Belt that lay dormant for many years. The measured Venezuelan campaign to delineate these deposits during the early 1980s has now begun to bear fruit, with the first oil flowing in 1998.

Besides these large heavy-oil deposits, the country also possesses large gas reserves that remain largely unexploited. These appear to be the subject of an upcoming round of licencing.

One of the most promising remaining plays lies in the poorly-explored deeper part of the Maturín Basin Tertiary section, where deep-water reservoirs may provide mainly stratigraphic traps within enveloping shales. In addition, the extent and the stratigraphy of this basin below the mountains to the north remain unknown and offer the possibility that accumulations exist there. Imaging and drilling these will be major challenges. Deeper structures involving Cretaceous and Tertiary objectives probably remain to be tested within the frontal fold-and-thrust belt.

Of the country's three main producing provinces, the Barinas-Apure Basin is the least prolific. For this reason, exploration, while active, is less mature than in the Maracaibo and Maturín Basins. The Andean flank of this basin is a continuation of the Llanos Basin fold-and-thrust belt where major reserves lie in the Cusiana - Cupiagua - Volcanera/Pauto/Floreña complex. However, great variations of stratigraphy and structural style occur along the Andean front, and the Barinas area so far has not yielded any major reserves other than the inverted *Guafita* structure.

Exploration on the Maracaibo Basin side of the Mérida Andes has located hydrocarbons, though not in great quantities. The North Andean front appears to be composed of basement-cored thrusts. Nevertheless, as long ago as 1956, gravity data were interpreted to indicate that this complex overrides the north Andean foredeep which may have some deep, sub-thrust potential. The deeper, southern part of the basin and its western flank remain poorly tested. The former probably is gas-prone; the latter may structurally be very complex.

The core of the inverted Falcón Basin remains poorly explored and structurally poorly understood. Its potential seems poor.

In the offshore areas, the Gulf of Venezuela remains virtually untouched by the drill. Seismic data provide some encouragement in the west, while in the east the plunging Urumaco Trough lies downdip from the onshore *El Mamón* field. Undeveloped oil lies in La Vela Bay and shows have been seen in the Cariaco Basin. The Carupano Basin contains several trillion cubic feet of gas, so far undeveloped. Apart from studies focussed on production of the latter for LNG, offshore activity has remained low and the province remains poorly explored except for the southern part of the Columbus Basin where gasfields are known, but have not been reported in the public domain. The Cariaco Basin especially merits further exploration, since only structural leads have been tested.

An interesting observation is that the kitchen areas for hydrocarbons in the Barinas-Apure and Eastern Venezuela Basins are still poorly understood. The literature describes several plausible models, but this plurality reinforces the foregoing statement. There is general agreement that the vast majority of reserves derive from Upper Cretaceous source rocks; yet, in the Eastern Venezuela Basin, these rocks are not known from the autochthonous subsurface and at outcrop they are overmature. This further indicates that the timing of generation and the paths of migration are speculative. These facts are often not acknowledged in literature that describes models with unwarranted confidence and fails to consider multiple models. This allows the possibility that further prospectivity is enshrouded in the general lack of understanding. By way of illustration, there is the growing recognition that significant source material may exist in Tertiary deposits, and that different types of organic material in the Cretaceous section may be capable of generation at differing stages of thermal evolution.

The adage states that where oil is known, more remains to be discovered. Venezuela has a lot of known oil.

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