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# Caño Limon Field

## Llanos Basin, Colombia

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### FIELD CLASSIFICATION

BASIN: Llanos

BASIN TYPE: Foreland

RESERVOIR ROCK TYPE: Sandstone

RESERVOIR ENVIRONMENT OF

DEPOSITION: Deltaic and Marine

RESERVOIR AGE: Tertiary and Cretaceous

PETROLEUM TYPE: Oil

TRAP TYPE: Convergent Wrench Faults  
with Associated Folding

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### LOCATION

The Caño Limon field lies on the border between Colombia and Venezuela at the north end of the Llanos basin of Colombia (Figure 1). Its name is derived from the Caño Agua de Limon, the small river running through the area. Recoverable oil reserves are estimated at 1.05 billion barrels underlying 8821 acres.

The field is in the Intendencia (state) of Arauca, which covers the northern part of the Llanos basin. The Llanos (plains) of Colombia are a vast, flat grassland sloping gently eastward from the foot of the Eastern Cordillera and are cut by tree-lined rivers. Some areas such as around Caño Limon are swampy. From April to November heavy rains soak the region, which is very dry the rest of the year.

The surface is entirely covered by recent deposits. Photogeology and Landsat analysis have not successfully defined prospects. Reflection seismic is the only effective exploration method prior to drilling.

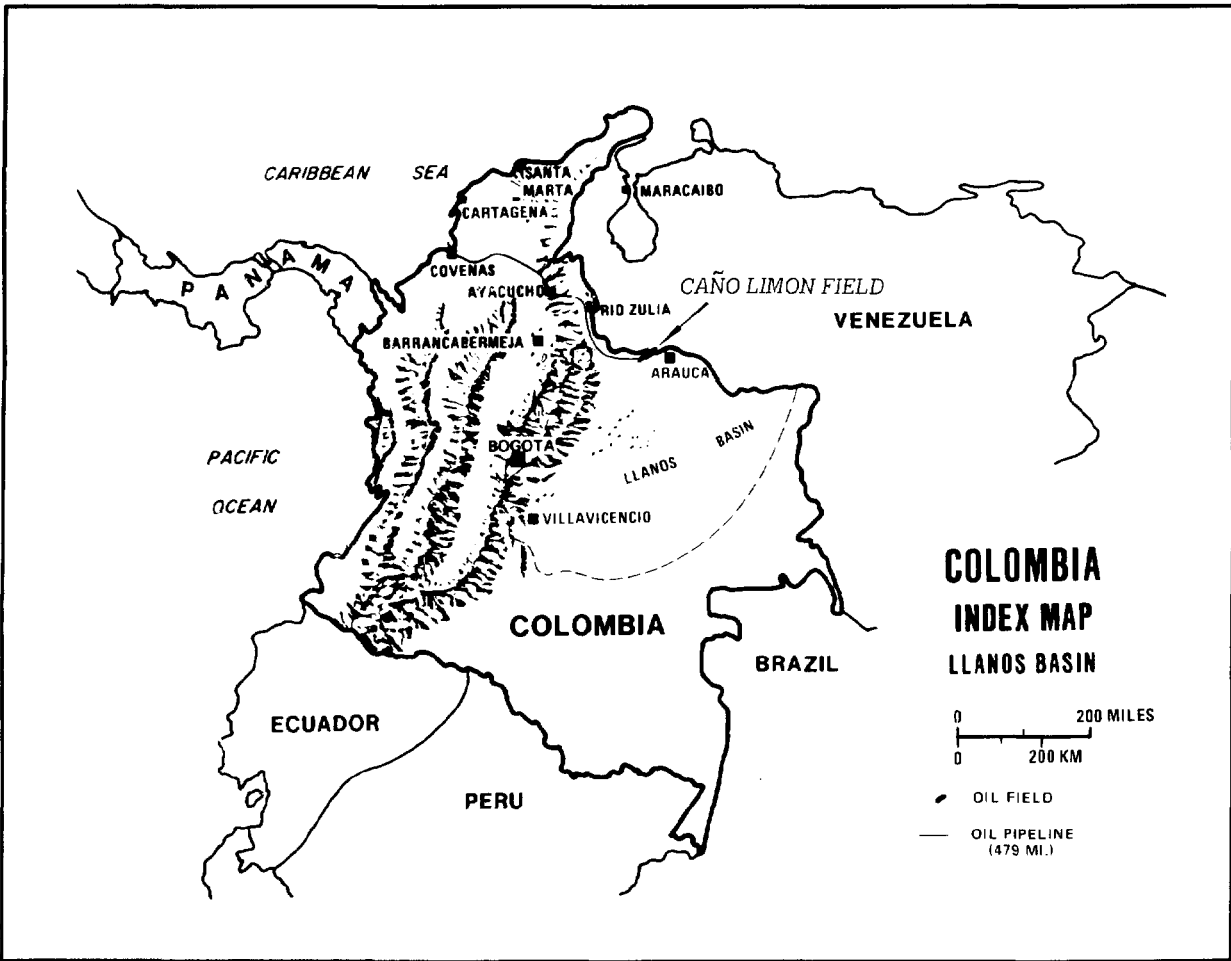
The only prior discovery in the northern Llanos basin was the Arauca field discovered by Intercol (Esso) in June 1980. This field is 75 km west of Caño Limon in the deeper part of the basin near the Andean foothills. It is a faulted domal structure in which four wells were drilled to depths ranging from 19,201 ft (5852 m) to 20,581 ft (6273 m). Initial reserve estimates of up to 200 million barrels of oil decreased after each additional well with Esso's current estimate being between 7 and 8 million barrels of oil.

### HISTORY

#### Pre-Discovery

Exploration of the Llanos Basin started in 1944 and was sporadic until the late 1970s (Figure 2). Occidental International Exploration and Production Company (Oxy) began exploration operations in the Llanos basin in July 1980 after signing contracts with Ecopetrol, the national oil company, on 11 June 1980 for five land blocks of 1 million hectares (2.47 million acres) each (Figure 3).

Vast areas of the basin remained totally unexplored or underexplored partly because of a widely held belief that oil source for the major east flank of the basin was deficient. This belief was supported by the report of a prominent research company that examined the oil source potential of the samples from a number of Llanos basin wells and concluded, "The Eastern Llanos does not contain the ingredients for commercial oil and gas." Also, sparse previous seismic lines had suggested that the east flank was virtually featureless. The exception was minor up-to-the-basin normal faulting that gave rise to the discovery in the Central Llanos by Elf Aquitaine and its partners of the small Trinidad field in 1974 (10 MMbbl of oil) and the Caño Garza field in 1979 (10.5 MMbbl of oil), shown in Figure 2.



**Figure 1.** Location map showing the position of the Caño Limon field in the Llanos basin. In Venezuela, the equivalent basin is named Barinas-Apure.

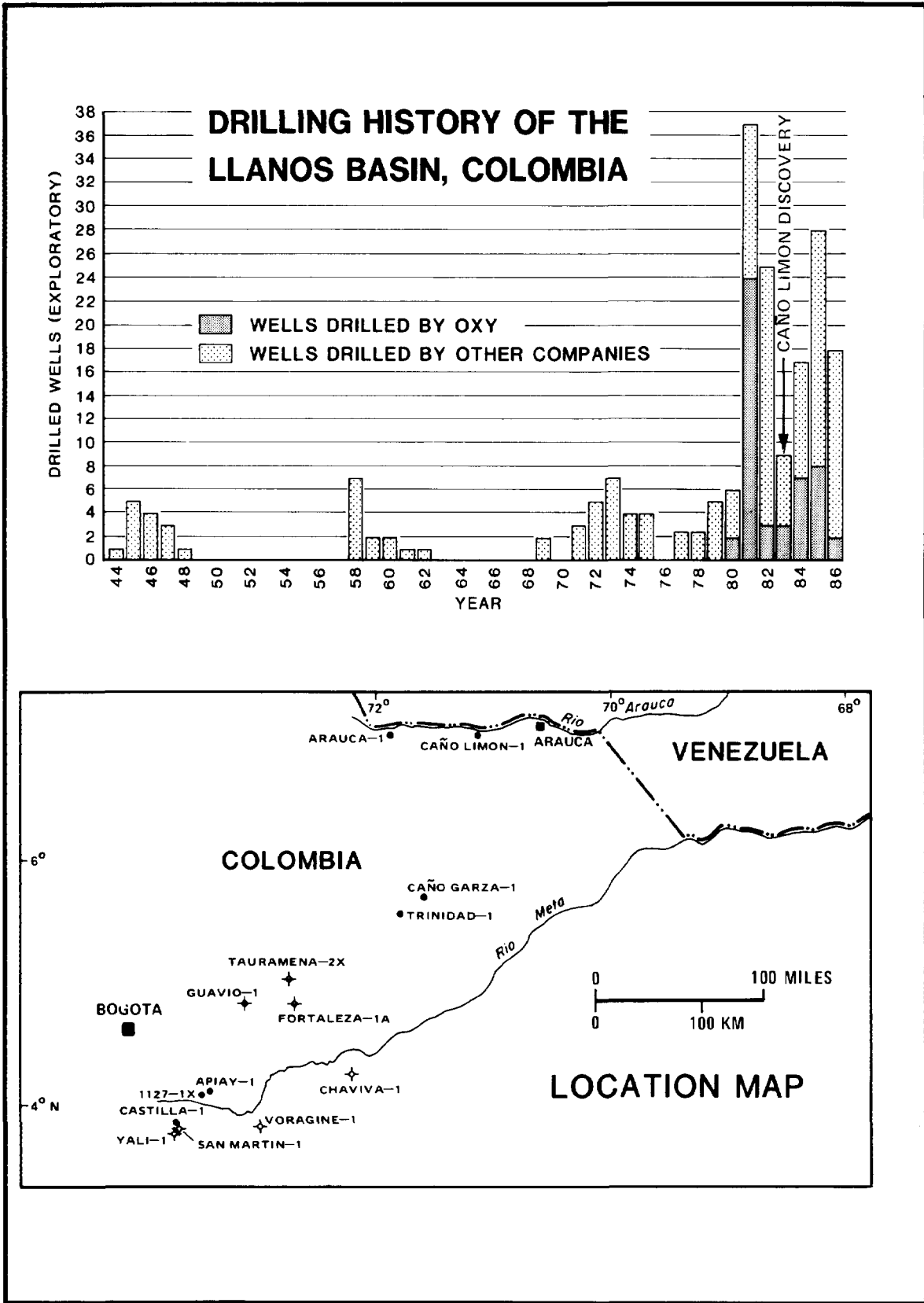
Low gravity oil had been found earlier by several operators in the southern end of the basin. The one commercial heavy oil discovery is the Castilla field found by Chevron in 1969. Intercol (Esso) had begun exploration for heavy oil in three blocks of 1 million hectares each in the southern end of the basin in April 1980.

In early 1980, a study of the basin was initiated by Oxy geologists to test the concept, based on experience in other sub-Andean basins, that a prolific early migration of oil should have occurred from Cretaceous or early Tertiary shales in the deep part of the basin prior to the Andean orogenic uplift (Miocene to Recent) of the Eastern Cordillera. Because of the many widespread permeable sands in the Cretaceous and early Tertiary, long-distance migration seemed likely and there appeared to be no limit to how far east oil might occur. Another premise was that no basin of this size could totally escape structural and stratigraphic complications and that

persistent exploration would find them. In summary, the major oil should be found in early traps on the east flank of the basin rather than in the young mountain front structures where most previous exploration had been focused.

The initial Oxy play was entirely conceptual because no prospects or even good leads were recognized from existing data. In the larger area covered by the five land blocks (Figure 3), some seven different trapping styles were visualized. The concept that led to the Caño Limon discovery was that the Arauca arch, plunging to the west-northwest along the Colombia-Venezuela border, should have associated structural or stratigraphic complications that could lead to trapping of oil (Figure 4). The arch should also have been an oil migration focus.

The presence of the Arauca arch had been interpreted but not completely confirmed by early workers (Zambrano et al., 1971). Using well and seismic data acquired since 1980, the present-day



**Figure 2.** Histogram of exploratory wells drilled in the Llanos basin from 1944 through 1986 and map showing the location of some of the more significant wells.



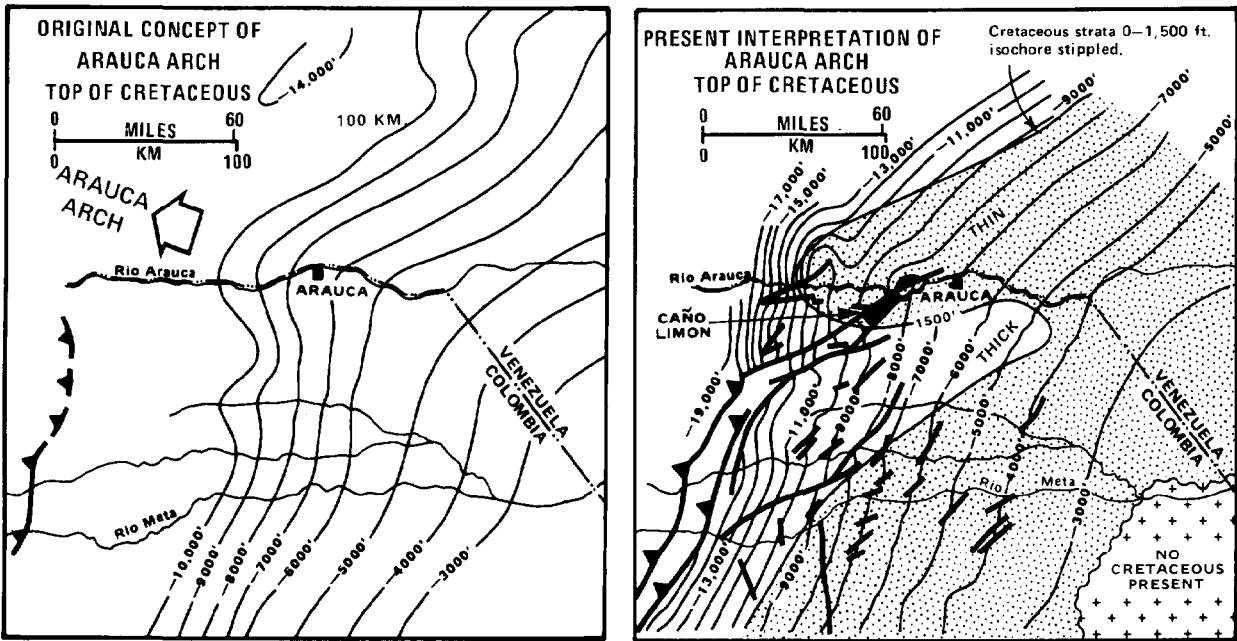
**Figure 3.** Location of the five blocks contracted by Occidental 1 July 1980. Each block is approximately 1 million ha (2.47 million ac).

structural interpretation of the top of the Cretaceous shows a broad westerly plunging nose similar to earlier concepts. The Cretaceous isochore thinning indicates a southwesterly plunging feature, probably related to major wrench tectonic processes (Figure 4). Whether these processes occurred during or after Cretaceous time is not clear.

In the first contract year (1980-1981), a seismic survey on about a 10 km grid was conducted over about 1600 km<sup>2</sup> in the northwestern part of the Cravo Norte and Rondon blocks near the Arauca arch. No seismic surveys had been conducted previously in this area. British Petroleum once had started a program over part of the area, but the program was canceled when the seismic contractor reported that swamps and boulders prevented the drilling of shot holes. The area is indeed swampy, but in the subsequent drilling of more than 25,000 shot holes, no boulders were reported!

The new Oxy seismic interpretations showed some nearly vertical, large displacement faults trending northeast-southwest, with growth on the low southeast side during Cretaceous and early Tertiary time (Figure 5). This was the first clue that something of significant interest was present in the area where Caño Limon was later found. At first these faults generated some excitement, but as it became clear that they were essentially parallel to the dip direction, doubts arose about their ability to form traps.

In the second contract year (1981-1982), the seismic grid was infilled to a roughly 5 km grid and expanded to cover about 1900 km<sup>2</sup>. Several potential low relief closures near the faults were inferred, but none were considered drillable. At this time oil prices had dropped from as high as \$40 to \$26 or \$28 a barrel, and Oxy, like most other companies, was reducing exploration expenditures world-wide. This led to the decision to seek a partner, or partners, on a farmout basis.



**Figure 4.** Comparison of interpretations of the Arauca arch in 1980 versus 1989. Although structure contours on top Cretaceous have a similar general shape, the

Cretaceous isochore indicates that a different structural shape was present during or shortly after Cretaceous time.

Meanwhile, 61 km of seismic line were recorded to try to improve the leads. Line CL-61.7 (Figures 6 and 7) was recorded parallel to and on the down-dropped side of the main northeast-southwest-trending fault (later named the Caño Limon fault) to check out a small lead (eventually the Caño Verde discovery) and to see if other similar features were present. This line showed a small rollover, the Caño Limon structure (Figure 6), which was interpreted to be a small four-way dip closure as shown by Figure 7.

When it was recognized that the apparent crest of the structure was under inaccessible swamp, a surface location on the natural levee of the Caño Agua de Limon was found and directional drilling was programmed. Another seismic profile (CL-68.3) was recorded from the well site to the high point on line CL-61.7, and a second line (CL-61.6) was shot to better define the structure. Instead of having at least some four-way dip closure the possible trap was found to be totally fault dependent (Figure 8). This did not help farmout efforts that were still being pursued.

## Discovery

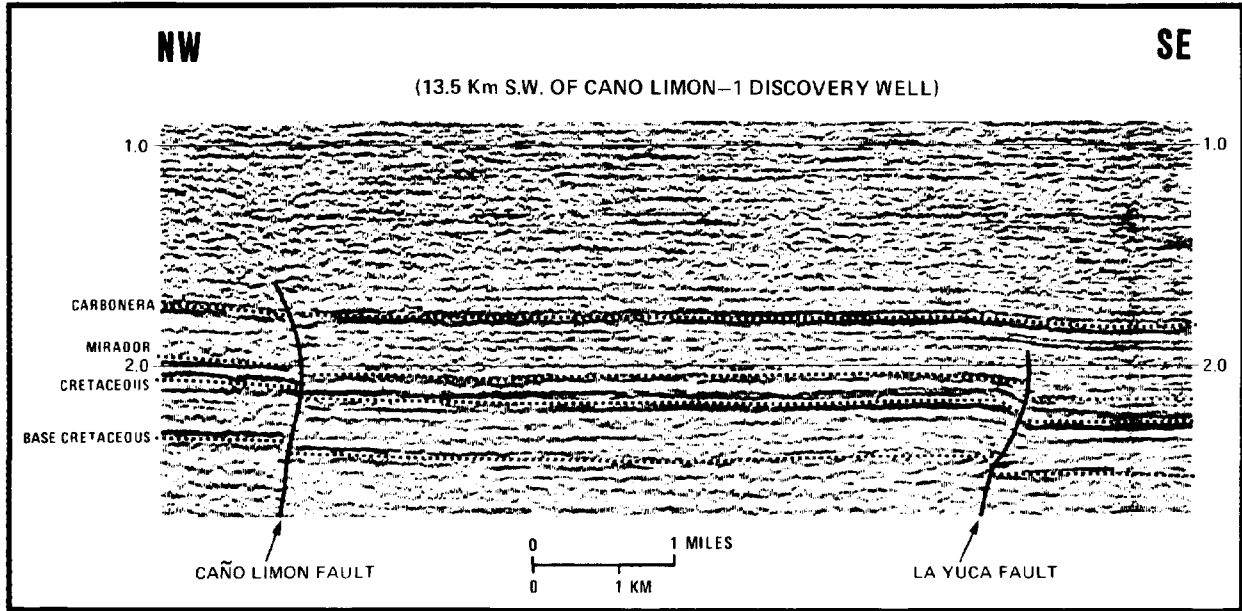
The Caño Limon-1 well was spudded on 20 March 1983 and directionally drilled to a total depth of 10,176 ft (3102 m) in the Paleozoic, reaching T.D. on 18 June 1983. The main objectives, the Mirador sands (Lower Carbonera/"Mirador"), were penetrated with no gas shows and only traces of fluorescence on a few sand grains. Hopes for a significant discovery seemed to

be fading. The logs, however, showed two sand intervals in the Mirador, each over 80 ft (24 m) thick, with resistivities as high as 2500 ohm-m (Figure 9). The combined test rate for these two zones was 10,690 bbl/day of 29.8° to 33.4° API oil from 171 ft (52 m) of net pay in the depth interval 8480 ft to 8705 ft (2585 to 2653 m) (drilled depths). No oil-water contact was present in these sands.

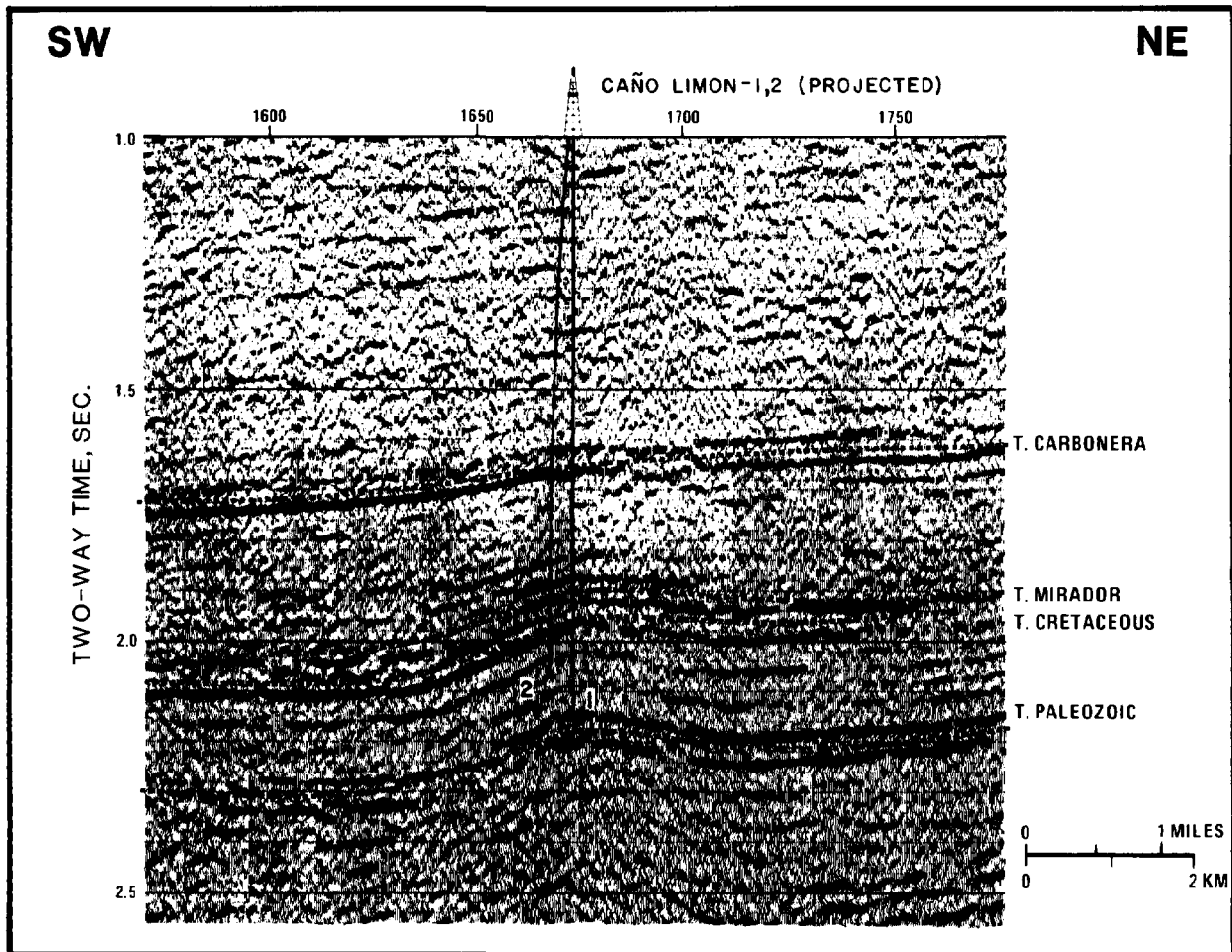
Immediately following completion of Caño Limon-1, Caño Limon-2 was directionally drilled from the same drill site to a location 700 m to the west on the west flank of the structure, where the oil-water contact was encountered. This well flowed 9848 BOPD from the lower Carbonera/"Mirador." The Caño Limon field was declared commercial in October 1983 with reserves then estimated at 64 MMbbl of oil (the official Ecopetrol estimate was 33 MMbbl of oil).

## Post-Discovery

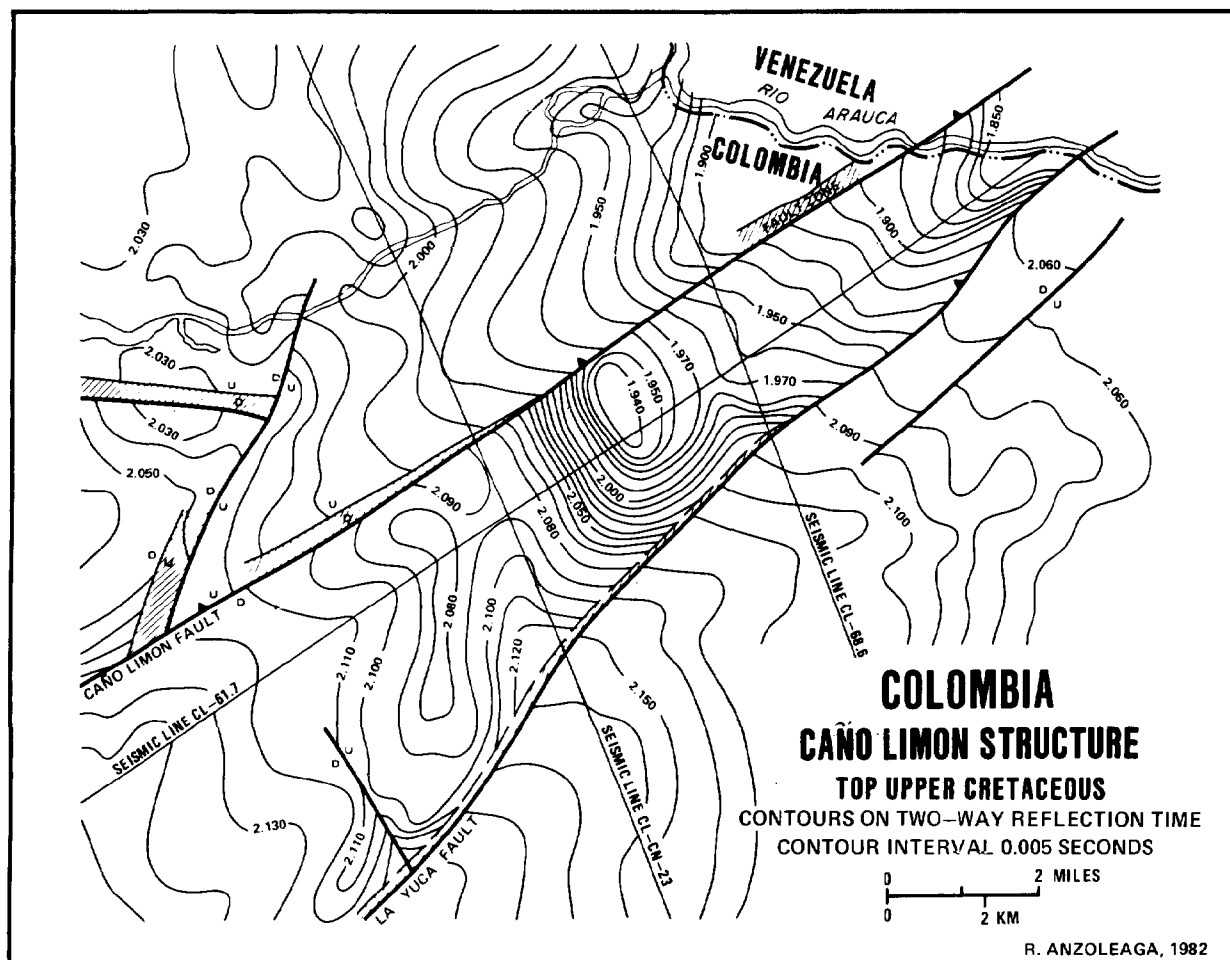
During the following dry season (1983-1984), locations were constructed for three additional wells. The Caño Limon-3 appraisal well on the east flank of the structure was spudded 9 June 1984, followed by the La Yuca-1 and Matanegra-1 exploratory wells on what were thought to be separate structures defined by additional seismic surveys made after the discovery (Figure 10). These three successful wells showed that the original Caño Limon structure is only a subsidiary fold on a much larger feature comprising a giant field.



**Figure 5.** Seismic section 13.5 km southwest of Caño Limon illustrating two of the major strike-slip faults, the convergence of which gave rise to the Caño Limon structure.



**Figure 6.** Portion of seismic section CL-61.7 (see Figure 7) that first revealed the Caño Limon structure.



**Figure 7.** Interpretation of the Caño Limon structure controlled by three seismic sections.

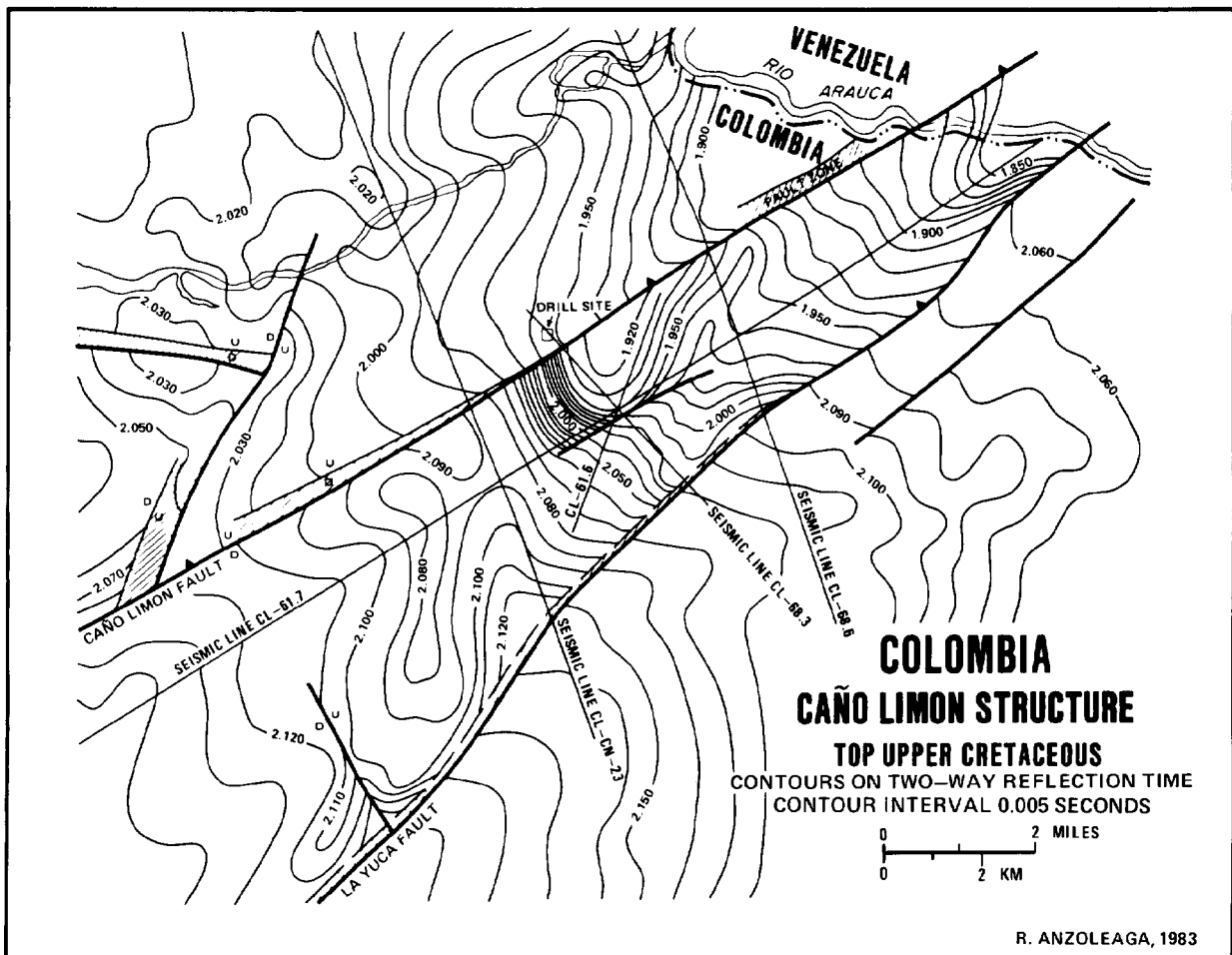
Development of the expanded field was begun in August 1984 with the drilling of six wells, five of which were successful. These were all directional wells drilled from the all-weather pads of Caño Limon-1, La Yuca-1, and Matanegra-1. The sixth well, the only dry hole in the field to date, is Matanegra-3, which found that a higher oil-water contact exists in the Matanegra horst block than in the remainder of the field (Figure 11). This well is now used for pressure observation. One of the directional wells, La Yuca-3, was directionally drilled from the Matanegra-1 drillsite to the syncline between Caño Limon and La Yuca to confirm that the oil accumulation is continuous between the two areas, as indicated by their having the same level of oil-water contact. The Palito-1 exploratory well was directionally drilled to a bottom-hole location north of the Matanegra fault and, finding only shows of oil, established that, at best, only a small amount of oil could be present south of the Arauca River in that area.

By the end of 1988, a total of 49 producers had been drilled on approximately 1 km (247 ac/well) spacing (Figure 11). Current estimates indicate that at least 75 producers will ultimately be needed to recover the 1.05 billion barrels of reserves.

Initially, it was expected that water injection might be required to supplement an expected natural water drive. Field performance has shown that a very strong natural water drive is present and no augmentation will be required.

## DISCOVERY METHOD

The Cravo Norte association contract area was chosen partly because of the belief based on published data (Zambrano et al., 1971) that the "Arauca Arch" existed along the border between Colombia and Venezuela. It was hypothecated that cross basinal arches are good places to look for oil and that the



**Figure 8.** Modified interpretation of the Caño Limon structure incorporating seismic sections CL-61.66 and CL-68.3.

Arauca arch might be a totally unexplored example. The types of hydrocarbon traps that might be present on the arch were unknown, but the maps (Figures 12 and 13) illustrate the concepts of the time. These maps are from the original recommendation of April 1980.

Since there were no surface geology, wells, or seismic data in the area, reflection seismic surveying was the most effective way to find out what lay under that vast swampy terrain. To say that the Caño Limon field was discovered as the result of successfully testing a geologic concept is perhaps not accurate in the specific sense that what was found was specifically predicted. On the other hand, the concepts of structural complications associated with the Arauca arch, source rock, early long-distance migration into early traps on the east flank of the basin, and presence of excellent reservoirs and seal facies were confirmed.

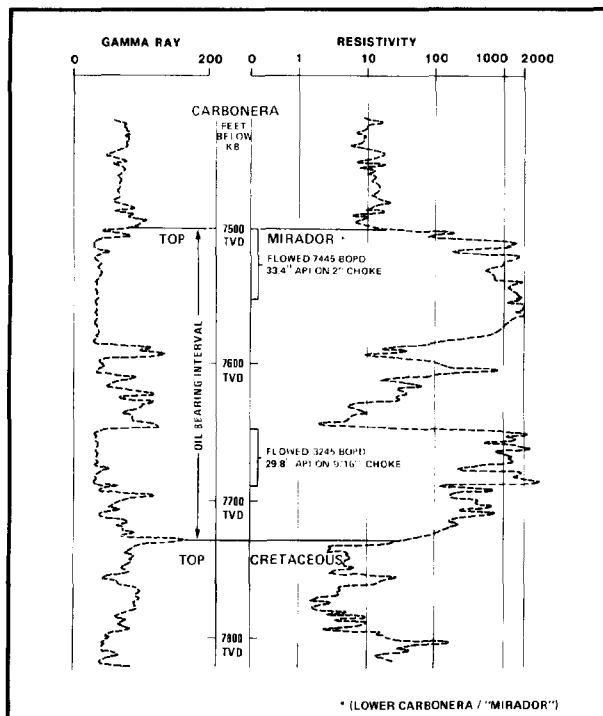
In evaluating the exploration potential of the Llanos basin in 1980, technical expertise had limited

application because of lack of data over much of the area. All the ingredients for oil except traps were indicated. At that point it became a conceptual play based on imagining all the types of traps that could logically be present and then performing reconnaissance exploration over broad areas to find geologic relationships that could lead to trapping conditions.

## STRUCTURE

### Tectonic History

Except for the young fold-thrust belt along the west side of the basin (Eastern Cordillera foothills), the Llanos basin is singularly lacking in structural complications. This fact was a major factor in inhibiting exploration. A system of late up-to-the-basin normal faults has formed numerous small oil traps. Fifty-two oil fields have been discovered in



**Figure 9.** Portion of the dual laterolog-gamma ray from Caño Limon-1 showing the oil-bearing sands of the Lower Carbonera/"Mirador."

these structures, 45 of which have reserves less than 10 million barrels and seven of which have reserves between 10 million and 20 million barrels. These structures are so subtle that they failed to elicit much interest from most companies until after 1980. Exceptions to the lack of structuring are the Apiay area where Ecopetrol has made a number of discoveries and the Caño Limon area.

## Regional Structure

The east flank of the Llanos basin has a truncated Paleozoic section overlying the granitic Guyana shield over about the western two-thirds of the basin (Figure 14). In the eastern areas of the basin, Paleozoic strata are not present and Cretaceous or Tertiary sediments lie on granite basement. The Paleozoic on the basin flank is limited to Cambrian-Ordovician age. Whether the lack of younger Paleozoic sediments is due to nondeposition or erosion is not known, but erosion was a major factor in reducing the thickness of the Cambrian-Ordovician rocks. A schematic cross section (Figure 15) shows how the formation of a post-Ordovician graben in the northern Llanos preserved a great thickness of Cambrian-Ordovician rocks, and that a subsequent post-Early Mesozoic orogeny preserved Jurassic-Triassic redbeds in down-faulted and downwarped tectonic elements in the area of Caño Limon. Whether or not these early major structural elements set the stage for the Oligocene wrench faulting that created the Caño

Limon trap is not known but the lineation directions are very nearly the same.

## Local Structure

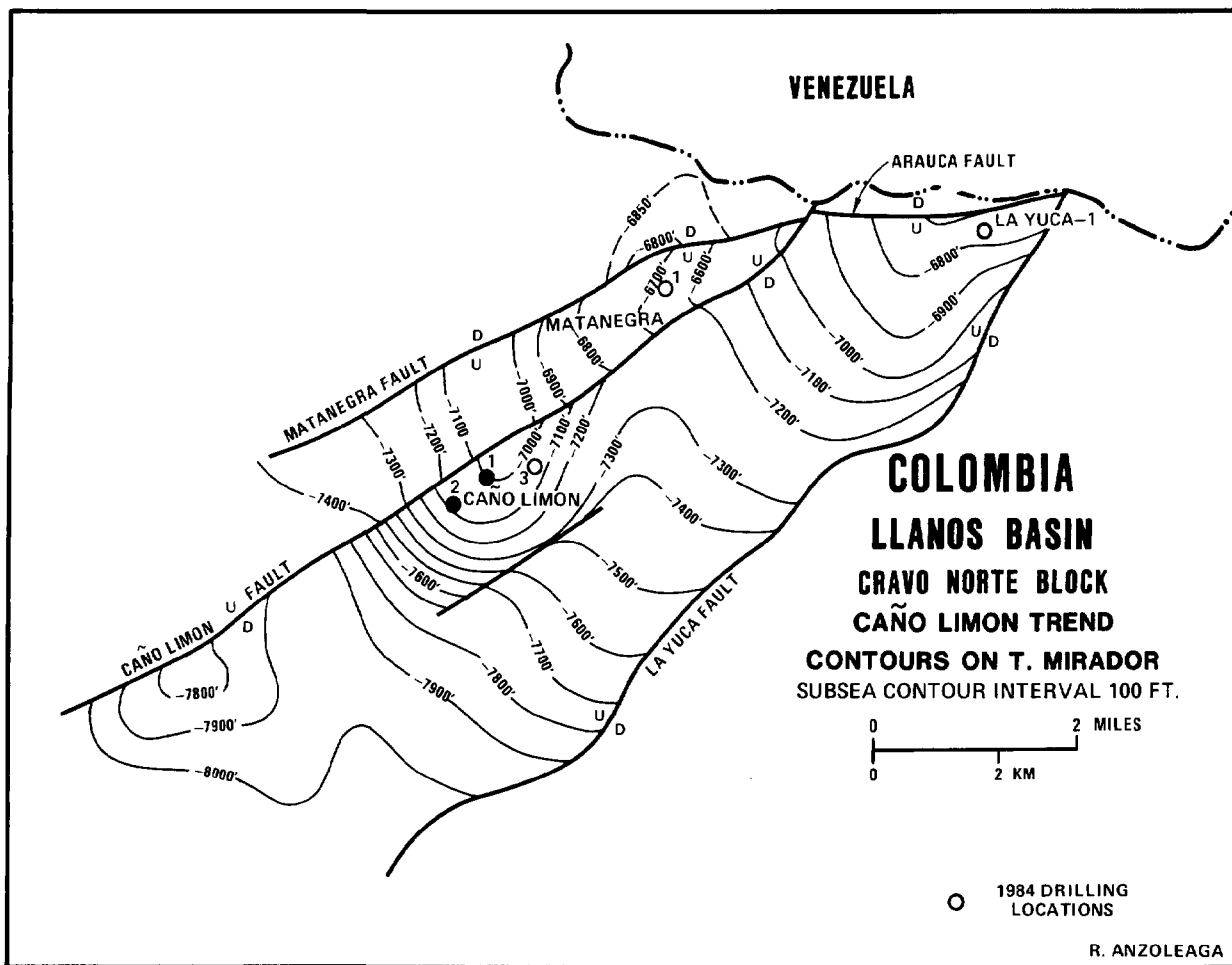
The major pre-Cretaceous unconformity left a vast peneplain that was blanketed by some 600-800 ft (180-240 m) of clean continental Albian to Cenomanian K-3 sands. These were followed by the marine-dominated deltaic sequences of the K-2 and the shallow-marine shelf to deltaic K-1 (the K-2 and K-1 are Coniacian to Campanian). Whether the absence of Maastrichtian and Paleocene strata in the Caño Limon area is the result of erosion or nondeposition is not known, but the lack of any discernible angularity between Campanian K-1 and Eocene lower Carbonera/"Mirador" suggests nondeposition. After deposition of the Eocene lower Carbonera/"Mirador" deltaic sands, the wrench movement along the Caño Limon, La Yuca, and Matanegra faults began or resumed. These faults converge at or northeast of the Colombia-Venezuela boundary, and apparently it was this convergence that gave rise to the folding of the Caño Limon structure. Movement on the main strike-slip faults continued into early Oligocene. The growing Caño Limon structure evidently was buried almost as rapidly as it formed because there appears to be no truncation of Eocene beds. Early Oligocene Carbonera sands and shales onlap the structure with resultant stratigraphic oil accumulations on the flanks of the Caño Limon and La Yuca portions of the structure.

A series of down-to-the-northeast normal faults (the Arauca fault and others, Figure 11) nearly perpendicular to the main strike-slip direction are present along the Arauca River, which is the boundary between Colombia and Venezuela. These faults have displacements of up to 350 ft (107 m) and in combination effectively form the updip limit of the Caño Limon field. The area between the Arauca fault and the Arauca River is called Caño Yarumal.

## STRATIGRAPHY

The stratigraphy of the field area is illustrated by Figure 16, which shows log character and interpreted depositional facies, and by Figure 17, which describes the lithology of all major units in the field area. The stratigraphy of the Paleozoic is not well known. The few wells drilled into Paleozoic have found mainly siltstones and shales with a few sandstones. Paleozoic sediments over the major part of the basin are well indurated but cannot be called metamorphic. Sandstones with porosities up to 22% have been seen, but the more usual values are in the 10% to 12% range. Whether adequate oil source rocks exist is a question.

With the exception of minor carbonates in the Paleozoic and Cretaceous, the Llanos basin is filled with sands, shales, and siltstones. Prior to the



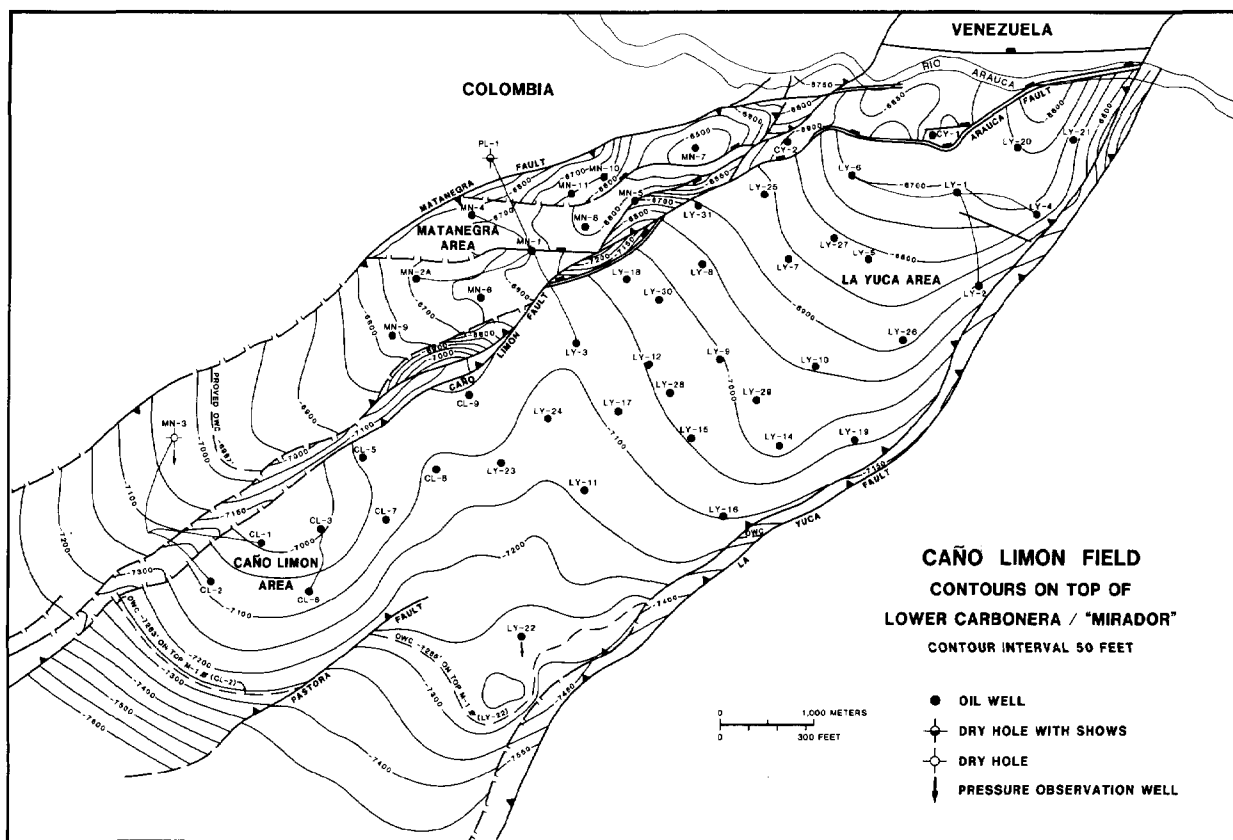
**Figure 10.** Locations of the three wells drilled in 1984 which led to the recognition that the Caño Limón field was only a small part of a much larger accumulation.

Andean orogeny, probably all sediments entering the basin were derived from the granitic Guyana shield to the east and southeast. A western source, the Central Cordillera, contributed sediments to the Magdalena Valley portion of the basin. After the onset of the Andean orogeny a probable dual eastern and western source was present that later became a totally western source as basinal sediments, now exposed in the Eastern Cordillera, were eroded and carried eastward.

Cretaceous units ranging in age from Albian or possibly older to Campanian are predominantly alluvial, deltaic, turbiditic, and basal transgressive sands. Shales are a minor constituent to the east, but the basal shaley equivalents to the continental/deltaic sands thicken into the basin and contain turbidites, as might be expected. Cretaceous sands are generally of very good reservoir quality. The major oil source of the Llano basin was in marine Cretaceous shales in the basinal depocenter, now uplifted in the Eastern Cordillera.

The Paleocene Cuervos-Barco shale-sand units are present in the western portion of the basin but terminate along an eastern pinchout, the position of which is controversial. The Barco sands are productive in Intercol's deep Arauca field.

The main reservoir, the Lower Carbonera/"Mirador," contains about 80% of the oil reserves in the Caño Limón field. The awkward name given this unit results from a compromise of some early stratigraphic miscorrelations. This unit, which has been a major exploratory target over most of the Llano basin, had traditionally been called Mirador. Work by the partnership of Elf Aquitaine, Hocol (Houston Oil Colombia), and LL&E (Louisiana Land and Exploration) in the early 1980s showed that the true Mirador existed only in the western part of the basin and that the major sand to the east is younger and is more likely a lower member of the Carbonera formation. This relationship was also recognized by the Venezuelans in wells drilled on their side of the border. The problem is compounded by the fact that



**Figure 11.** The Caño Limon field in late 1989.

the former Mirador unit is Eocene, as is the true Mirador to the west, whereas the remainder of the Carbonera is Oligocene, changing upward to Miocene. The term Mirador is so infused in the records that it is difficult to abandon, and yet the fact that this unit more properly belongs to the Carbonera should be recognized. Some authors have made the full transition to calling this unit simply Lower Carbonera.

In any event, the Lower Carbonera/"Mirador" is present over essentially all the Llanos basin as a major regressive unit. It appears to be a series of stacked deltaic and alluvial sands with few shales. It is an excellent reservoir with thickness of about 200 to over 500 ft (61 to 152 m).

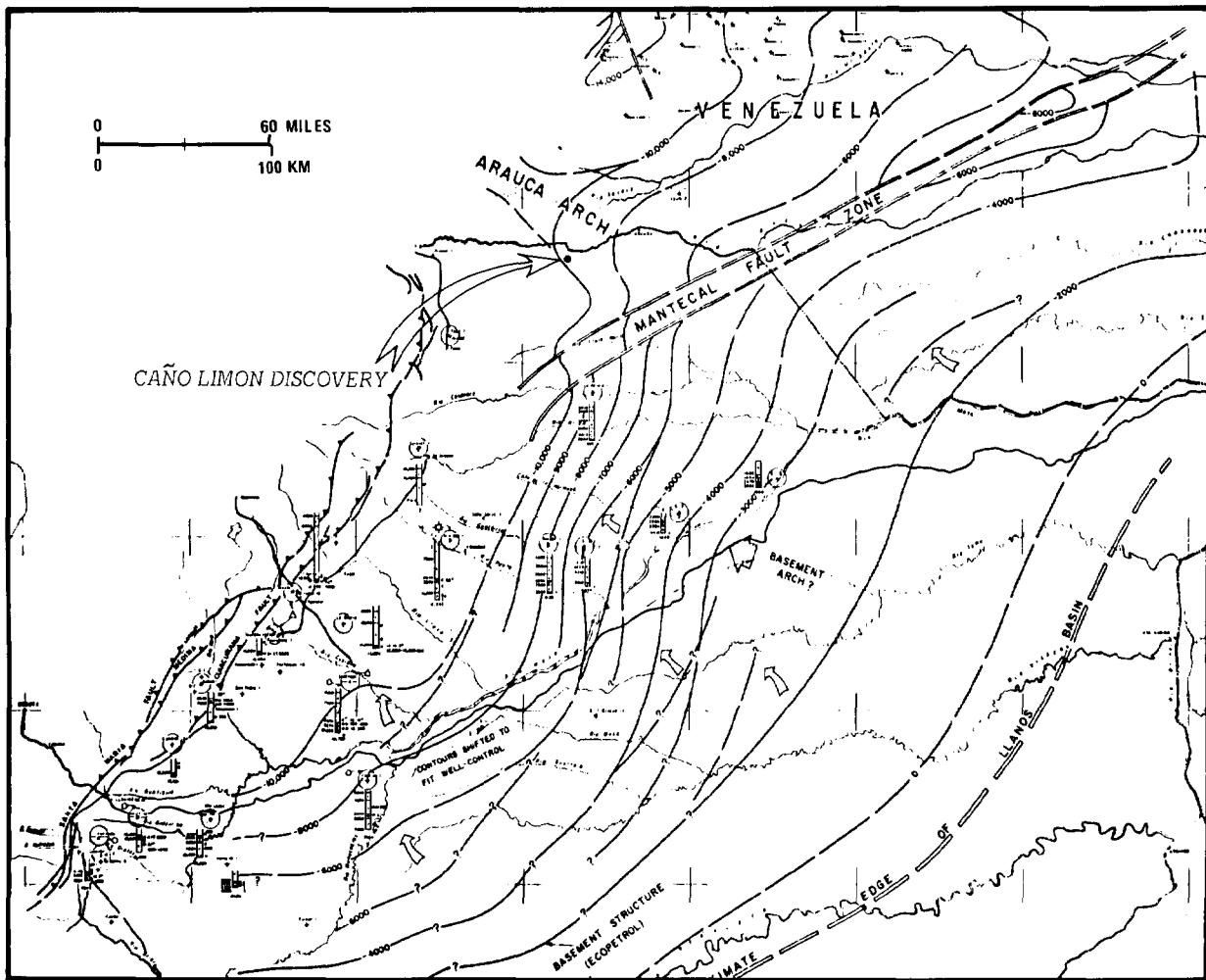
The internal stratigraphy of the Lower Carbonera/"Mirador" is of prime importance in the exploitation of the field in that the degree of continuity will govern the recovery efficiency and the number and placement of development wells. Studies to date (Parker, 1986; Cleveland, 1988) indicate that continuity is generally good in all the Caño Limon reservoirs and that recovery efficiencies will exceed 50% with good reservoir management and the strong natural water drive.

The Carbonera formation is Oligocene in the lower part and appears to be Miocene in the upper part. It incorporates three to four shaly transgressive units and the same number of regressive sandy units. The sandy regressive units are predominantly deltaic with coal swamp deposits and thin coal beds that give the formation its name. Within the prodelta and basinal shales are found some thin sands that are probably turbidites.

Oil has been found at several levels of the Carbonera, but mainly in the lower sands just above the Lower Carbonera/"Mirador."

Overlying the Carbonera is the Miocene Leon shale, a varicolored claystone with thicknesses from 560 to 785 ft (170 to 239 m). In the northern Llanos near Caño Limon it contains numerous sand interbeds, making its upper boundary difficult to pick. This is the most ubiquitous shale of the basin but to date seems to have no economic significance because no oil is known to be trapped in the sands immediately beneath it.

Above the Leon shale is a thick easterly thinning wedge of sands and shales of the Miocene to recent Guayabo formation. No hydrocarbon potential is known to be present in this formation.



**Figure 12.** Portion of map taken from original Llanos recommendation of April 1980. Reproduced at reduced scale without change. Contours on basement in feet

subsea. The Arauca arch and Mantecal fault zone were features of interest in the recommendation. The illegible details are not important to the play concepts.

## TRAP

Trapping of oil in the Lower Carbonera/"Mirador" (the main reservoir) and the Cretaceous K-1 and K-2A zones depends on the three main strike-slip faults (Caño Limón, La Yuca, and Matanegra) for lateral seals (Figure 18). The updip seals are the convergence of the Caño Limón and Matanegra faults for the Matanegra block and the Arauca cross fault system in the Caño Limón/La Yuca block.

All top seals in the field are shale. The downdip limits to the southwest are oil-water contacts. In the Carbonera C-5 sands, which onlap the older Lower Carbonera/"Mirador" structure, the trapping is stratigraphic.

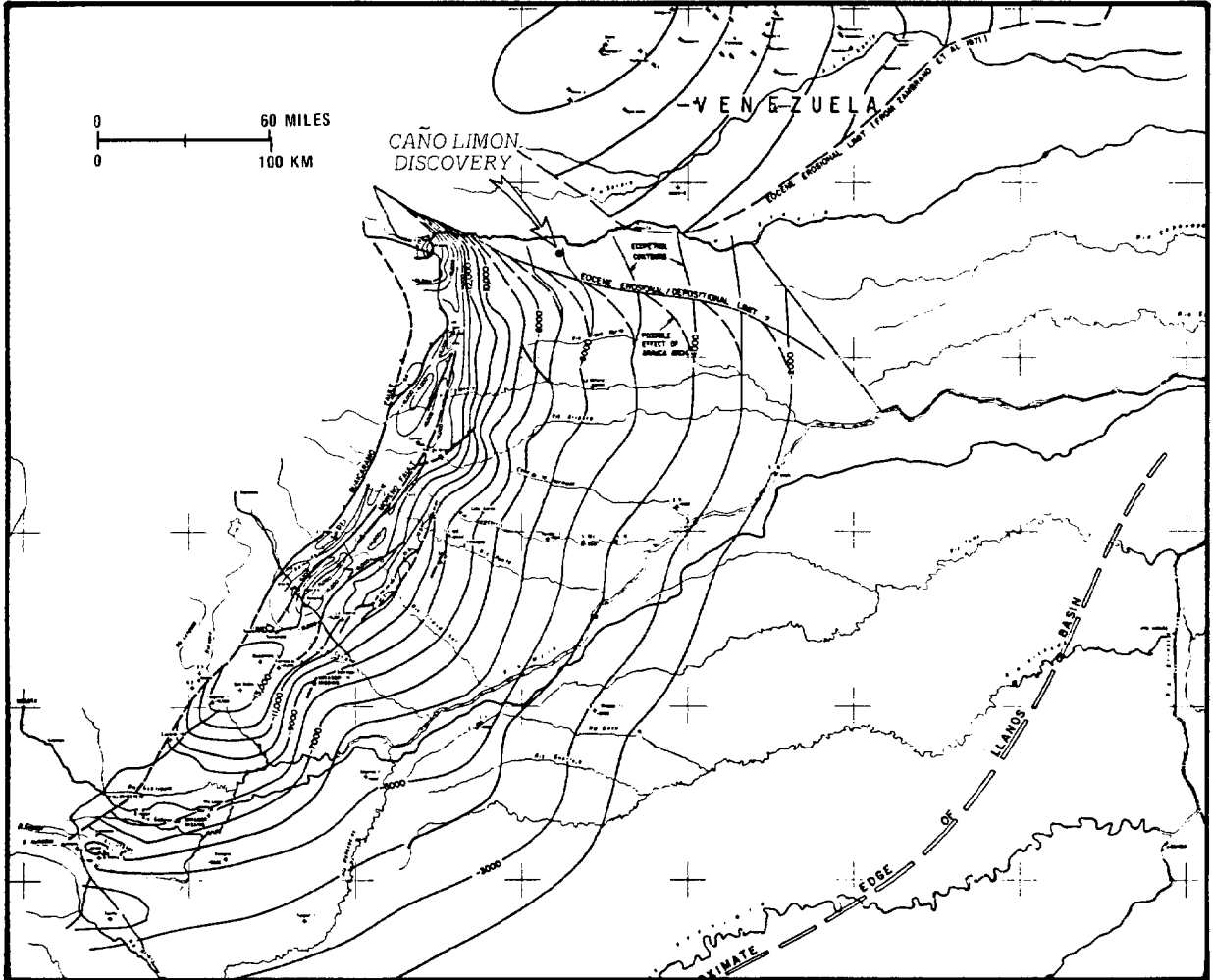
The trapping system is modified by a hydrodynamic gradient from northwest to southeast. A 0.3

to 0.6° southeasterly tilt to the oil-water contact has been documented in the Caño Limón and La Yuca area. The differences in potential across the main strike-slip faults reinforce the trapping capacity of the faults, resulting in greater oil columns on the southeast sides than on the northwest sides.

## Reservoirs

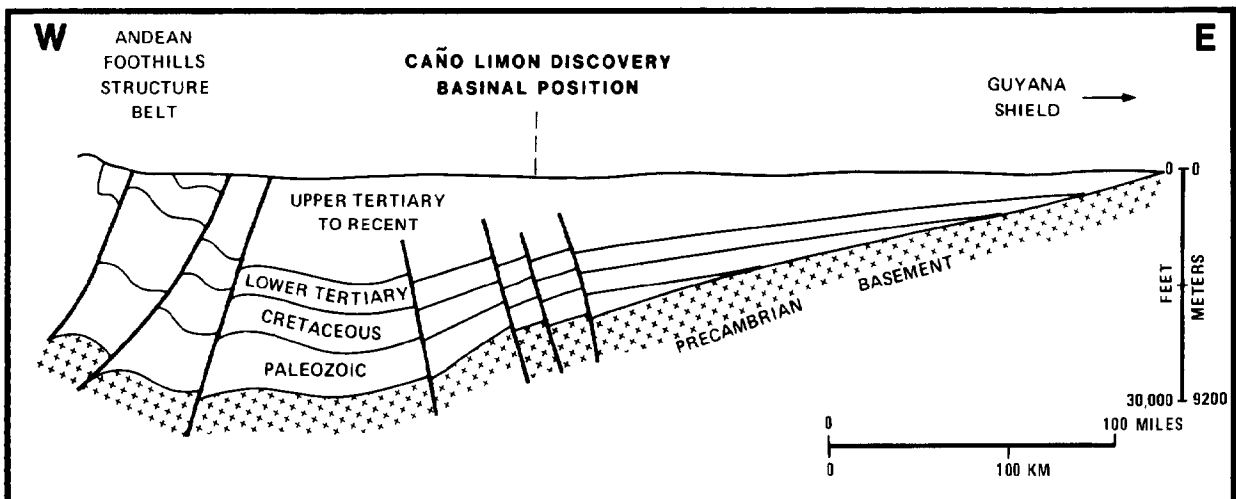
### Conventional Cores

Upon discovery of the field, Oxy immediately began an extensive conventional coring program that continues to the present. Thus far, 11 wells have been cored with a total recovery of 2226.4 ft (680 m) from all productive intervals. Cores were subjected to conventional and special analysis and

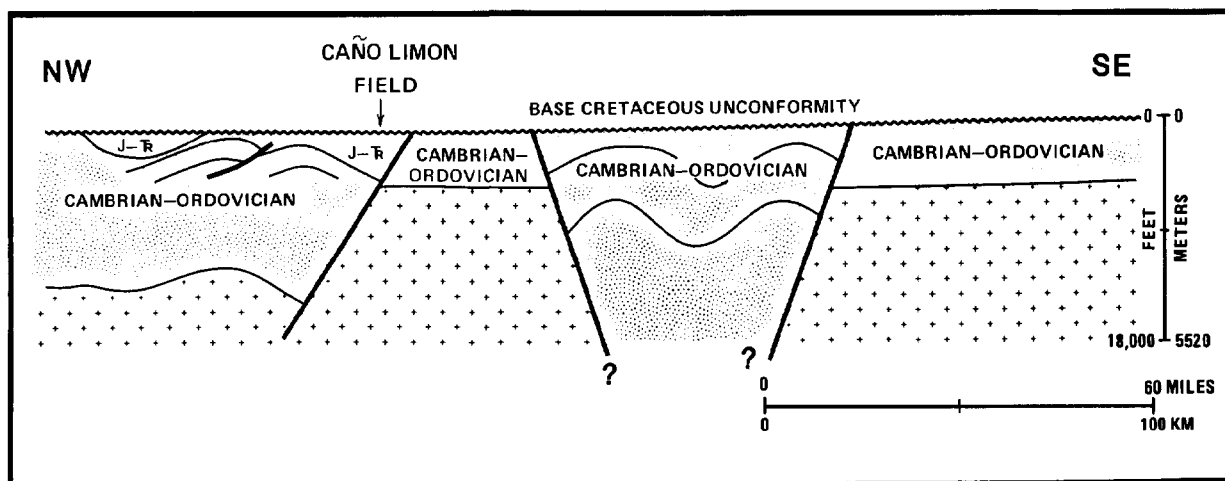


**Figure 13.** Portion of map from original Llanos recommendation of April 1980. Reproduced at reduced scale without change. Contours are on top of Mirador in feet subsea. This map illustrated the then conceived

structural and stratigraphic effects of the Arauca arch. Although these concepts did not prove to be correct, they served to direct exploration efforts to the right area.



**Figure 14.** Schematic cross section of the Llanos basin.



**Figure 15.** Schematic cross section illustrating pre-Cretaceous structural events and stratigraphic preservation.

described in terms of depositional environments (see core photographs, Figure 19).

A Caño Limon field depositional model derived from core interpretations is illustrated in Figure 20. Core descriptions suggest a separate depositional regime for each producing formation. The Cretaceous K-2A reservoir consists of wave-dominated deltaic sands having high continuity parallel to the coastline. The Cretaceous lower K-1 comprises marine shales with interbedded wave-dominated delta sandstones, tidal-channel sandstones, and inner-shelf sandstones. Lower Carbonera/"Mirador" is interpreted as a sequence of river-dominated deltas, and the upper Carbonera as continental lower- to upper-deltaic plain. These environments are discussed in detail below.

#### **Cretaceous K-2A**

Lower shoreface sandstones comprise 56% of Cretaceous K-2A reservoirs, and upper shoreface sandstones comprise the remaining 44%. A shallow-marine origin for both facies is supported by glauconite concentrations that can exceed 10%. Lower shoreface sandstones are very fine to fine grained and are the poorer quality reservoir rock, owing largely to bioturbation (Figure 19A). Burrows are frequently clogged with kaolinite. Upper shoreface sandstones are fine grained but not bioturbated, and thus, uniform planar-tabular cross beds and thin clay laminae have been preserved (Figure 19B). Shoreface sandstone reservoirs are noteworthy for extensive coastline-parallel continuity and the absence of significant lateral fluid movement barriers.

Vertical fluid movement barriers are present in the K-2A. There are two main kinds: (1) marine and interdistributary bay shales and (2) sandstones

cemented with calcite that probably derived from dissolution of adjacent bivalve shell beds.

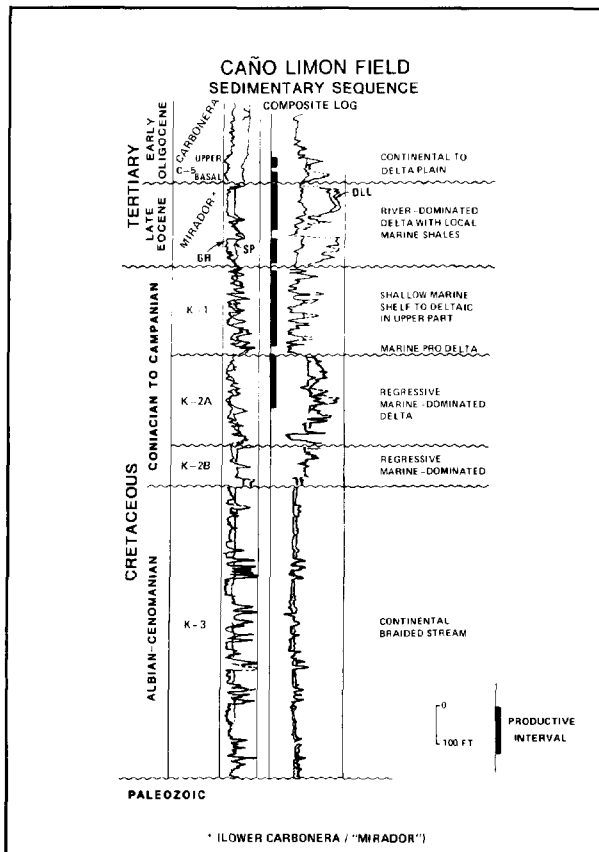
#### **Cretaceous Lower K-1**

The marine lower K-1 Formation contains a higher proportion of nonreservoir to reservoir rock (69%) than found in the K-2A Formation (23%). Nonreservoir lower K-1 deposits are primarily marine and interdistributary bay shales and, secondarily, shell beds and calcite cemented sandstones as in the K-2A. Reservoir deposits consist of marine inner-shelf (Figure 19C) shoreface and tidal-channel sandstones. The sandstones are all very fine to fine grained with minor glauconite. Kaolinite occurs in varying amounts and reduces reservoir permeability. It occurs primarily as burrow fillings where it can form lateral barriers in otherwise fairly continuous sandstones. The only high-quality K-1 reservoirs are those with few or no burrows.

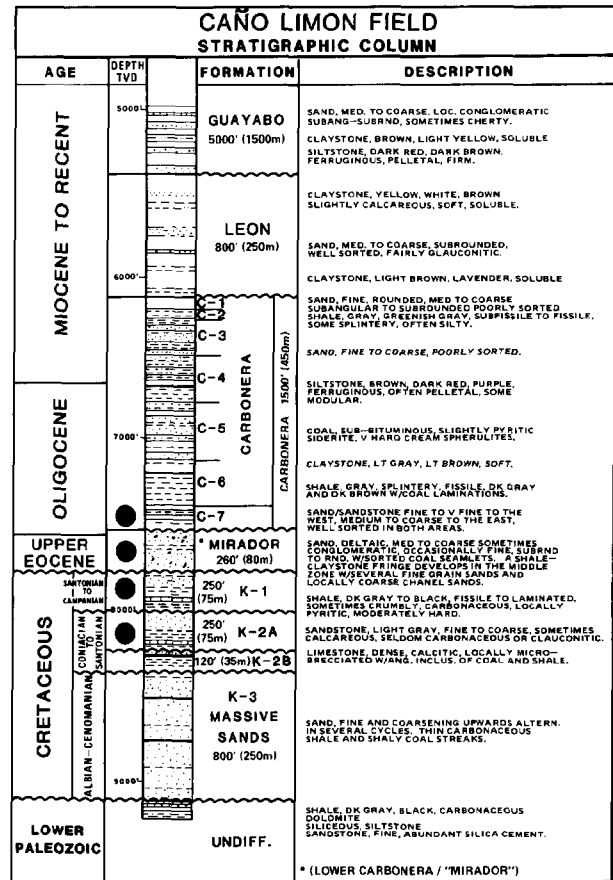
Interbedded marine and interdistributary bay shales separate the lower K-1 vertically into six sand members. The lowermost 60-100 ft (20-30 m) of lower K-1 is the continuous marine La Yuca shale, which separates the lower K-1 and K-2A into different hydrodynamic regimes with separate oil-water contacts.

#### **Lower Carbonera/"Mirador"**

The Eocene-Oligocene Lower Carbonera/"Mirador" Formation is the main Caño Limon reservoir, exhibiting the most permeable sands and 74% of total oil-in-place (80% of recoverable reserves). Deltaic distributary channel sands comprise 68% of Lower Carbonera/"Mirador" reservoirs. Channel deposits exhibit sharp erosional basal contacts with basal coarse sand and gravel and moderate- to high-angle



**Figure 16.** Composite log from the Caño Limon field illustrating sedimentary sequence and depositional environments.



**Figure 17.** Stratigraphic column for the Llanos basin and Caño Limon field.

and planar-tabular cross bedding (Figure 19D). Moderately to poorly sorted fining-upward sequences are present but are often obscured or repeated owing to sand-on-sand channel stacking.

An additional 24% of Lower Carbonera/"Mirador" reservoir rocks are low-energy channel-fill sandstones, which typically overlie or grade laterally into distributary channel sandstones. Low-energy channel-fill sandstones are fine grained, well sorted, and ripple bedded. Occasional bioturbation may indicate shallow-marine or brackish water conditions (Figure 19E).

An abrupt termination of channel flow is represented by channel abandonment sediments. Interlaminated clay with minor very fine to fine-grained sand filled the stagnant channel depressions. Sandier portions are often burrowed. Channel abandonment fills are mostly nonreservoir units, forming localized barriers that extend only as far as the filled channel depression.

Distributary mouth bars constitute 6% of the Lower Carbonera/"Mirador" reservoir sands, having been partially to completely eroded by the distributary channels. Gradational contacts with underlying

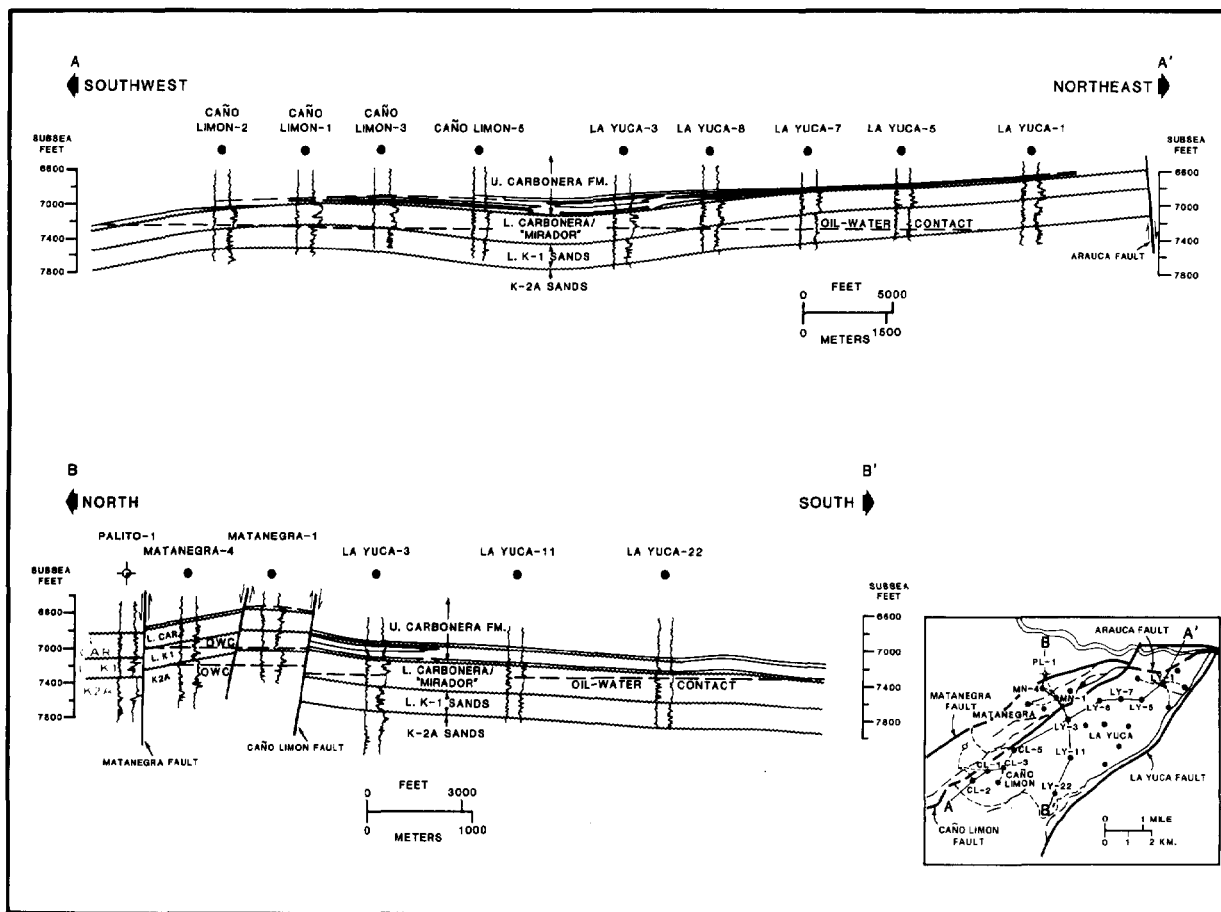
prodelta shales and abrupt erosional contacts with overlying distributary channels are characteristic (Figure 19F). The bar sands are fine grained and moderately well sorted, with upward-decreasing clay content and increasing grain size. Low- to high-angle planar-tabular bedding and partial cross-bedding to horizontal or wavy locally burrowed beds are present.

Of minor significance are the Lower Carbonera/"Mirador" estuary fill, crevasse splay, and overbank deposits, all of which are typically interbedded sand/shale sequences with fair to poor reservoir quality.

Nonreservoir rocks include marine, interdistributary bay and prodeltaic origin shales, and flood plain clays.

### Upper Carbonera

The upper Carbonera is composed primarily of flood plain clays that serve as the seal for Lower Carbonera/"Mirador" reservoirs. This formation also contains some relatively discontinuous fluvial or distributary channel sandstones with good reservoir properties, which are similar to distributary channel sandstones of the Lower Carbonera/"Mirador" (Cleveland, 1988).



**Figure 18.** Structure section across the Caño Limon field. Dip section A-A' shows trapping relationships in the Caño Limon-La Yuca area. Strike section B-B' shows relationships of Matanegra and La Yuca areas.

## Petrophysical Characterization

Productive formations are characterized below as to average porosity, permeability, water saturation, oil saturation, and net sand.

Average porosity is 23-25% (all primary) with a range of 12-32%, economic cutoff of 14% (from logs and stressed conventional cores).

Average permeability is 1450 md with a range of 10-8000 md; economic limit is approximately 10 md (from stressed conventional cores).

Average  $S_w$  is 21-42% with a range of 5-70%; economic cutoff is 50-70% depending on formation (from logs).

$S_{or}$  is 17-29% depending on zone.

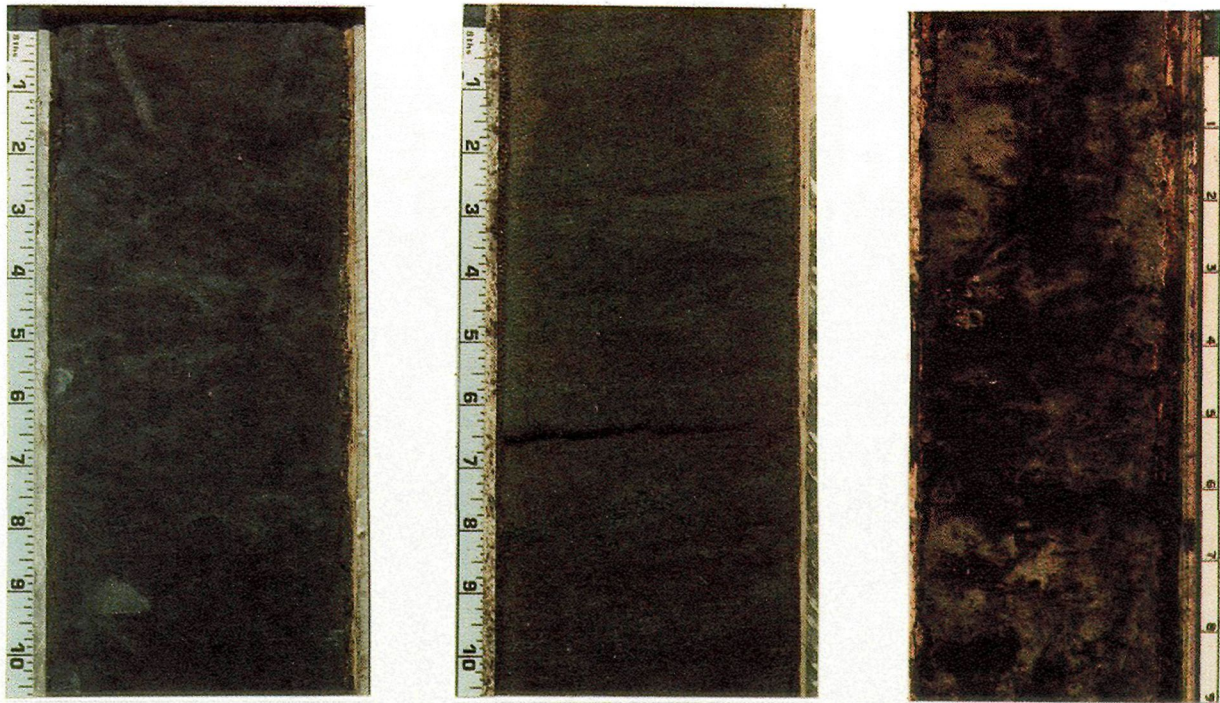
Average net sand thicknesses: upper Carbonera, 7 ft (2 m); Lower Carbonera/"Mirador," 144 ft (44 m); K-1 86 ft (26 m); K-2A, 168 ft (51 m).

All porosity is primary at Caño Limon. There has been no significant diagenesis of the rocks with the exception of very localized growth of kaolinite in intergranular pore spaces (Figures 21 and 22).

Average petrophysical parameters have been determined for the principal depositional environments (Figure 23). Porosity does not show significant variation from one environment to another, but clay volume and water saturation increase significantly in poorer quality environments. The increasing water saturation reflects a decreasing grain size. Finer grains have a higher percentage of surface area per unit volume than coarser grains and so exhibit a proportional increase in bound or connate water (Cleveland, 1988).

Capillary pressure curves have been determined from core plugs and plotted by environment. Four samples from Caño Limon-3 have been plotted in Figure 24 to illustrate the different depositional environments. This example suggests that oil-water transition zones will be shorter in high-quality distributary channel sands than in low-quality prodelta sands.

Caño Limon well performance indicates that geological heterogeneity has a significant effect on the pattern of water invasion in the reservoir (Figure



A

B

C



D

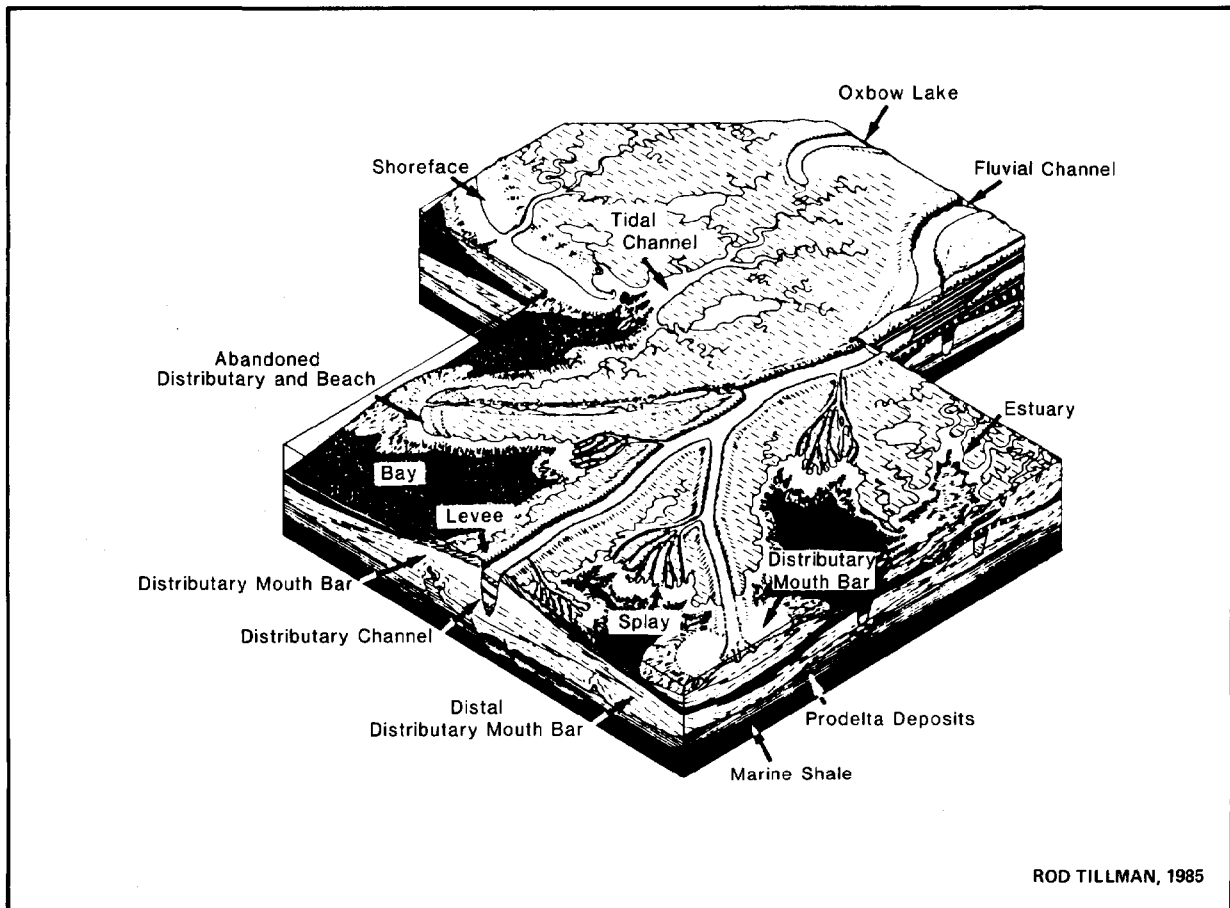


E



F

**Figure 19.** (A) Cretaceous K-2A: Lower shoreface sandstones are very fine to fine grained and glauconitic. Burrows filled with clay result in mottled oil stain. (B) Cretaceous K-2A: Upper shoreface sandstones are fine grained and glauconitic. Because they are unburrowed, uniform planar-tabular cross beds and thin laminae are preserved. (C) Cretaceous lower K-1: Burrowed inner-shelf/lower-shoreface sandstone. (D) Lower Carbonera/"Mirador": Distributary channel sandstones have basal coarse sand and gravel and moderate- to high-angle and planar-tabular cross bedding. (E) Lower Carbonera/"Mirador": Low-energy channel fill sandstones are fine grained, well sorted, and argillaceous. (F) Lower Carbonera/"Mirador": Distributary mouth bar sandstones are fine grained, well sorted, and planar-tabular laminated.



**Figure 20.** Depositional model showing most of the depositional environments interpreted from cores and logs.

25). Geological factors affecting sweep efficiency include:

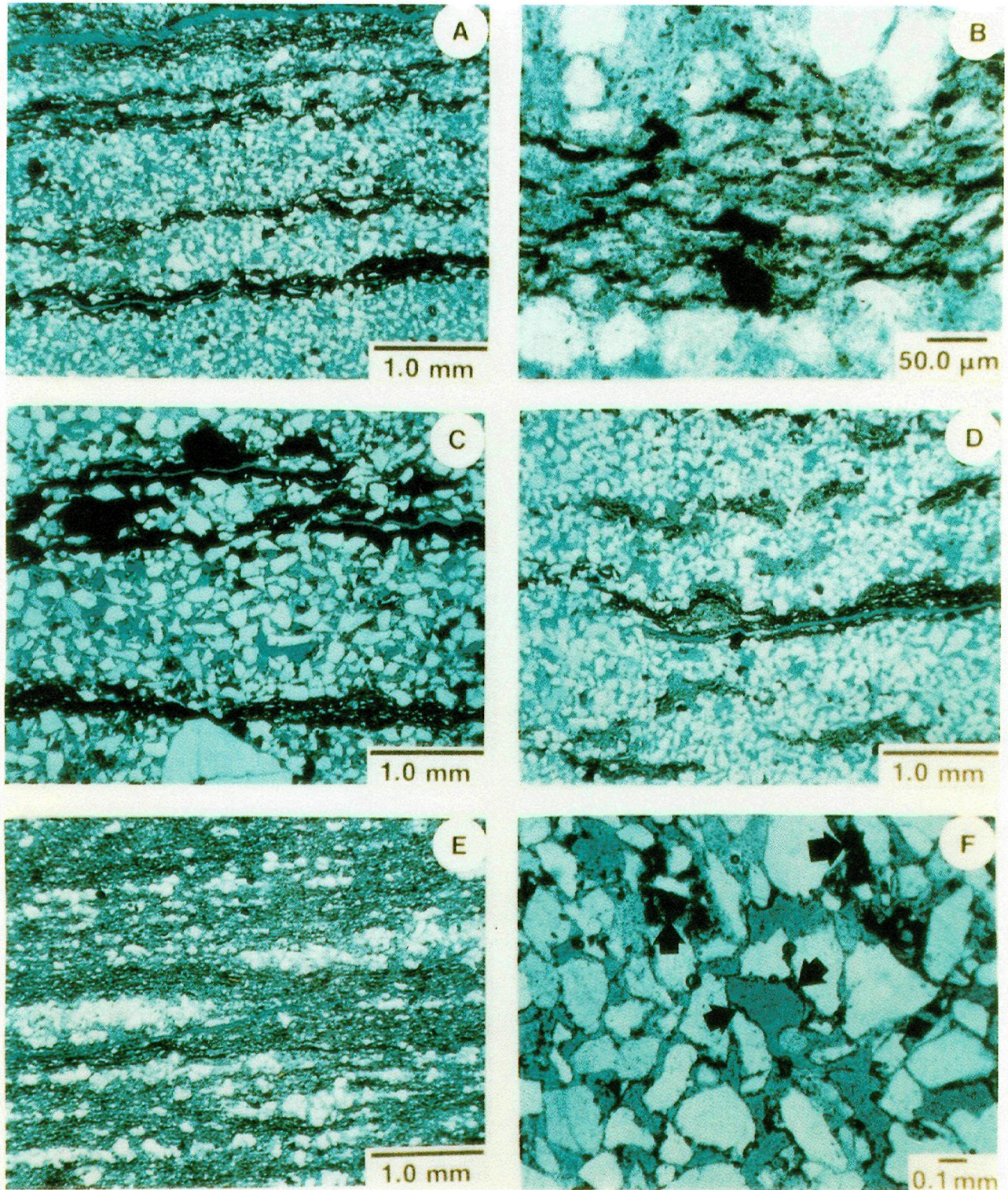
1. Areal permeability variation in reservoir zones that is related to areal variations in depositional environments.
2. Vertical permeability and layering distributions within each zone as related to depositional environment.
3. Vertical permeability within individual sands as affected by discontinuous shales or other discontinuous permeability features.
4. Very high capacity flow paths of probable limited extent and volume within portions of the reservoir. (Examples might be thin, high permeability layers such as narrow channel sands, faults, or combinations of these.)
5. Vertical permeability magnitude and variation across the apparently continuous mappable shales separating major reservoir zones.
6. Water influx locations, including fault plane channeling of water.

7. Communication across faults and between different sand units.

8. Lateral barriers within sand layers, including channel edges, abandoned channel clay plugs, and kaolinite filled burrows.

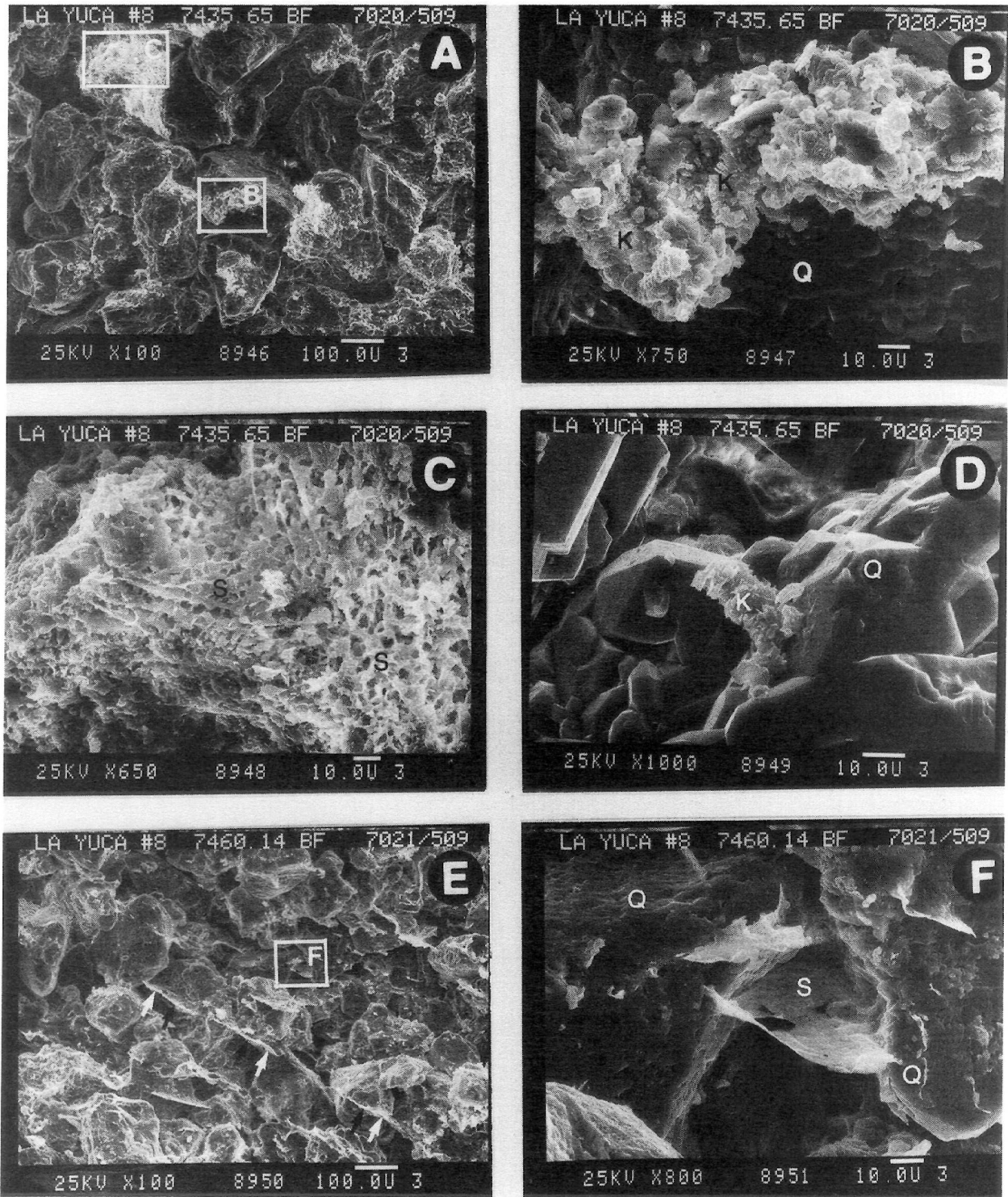
### Faults

The Caño Limon accumulation is trapped by updip closure against sealing faults. The northeast-trending Caño Limon wrench fault has probable right-lateral displacement of a few kilometers and variable vertical displacement of 0 to 500 ft (0-150 m). It divides the field into two major fault blocks: the uplifted wedge-shaped Matanegra block on the northwest, and the Caño Limon-La Yuca block to the southeast (Figure 11). The latter block contains the Caño Limon and La Yuca structural highs. Subparallel to the Caño Limon fault are the Matanegra and La Yuca wrench faults, which provide sealing lateral field boundaries and exhibit nearly vertical to reverse motion displacements. Updip closure of the Caño Limon-La Yuca area is against



**Figure 21.** Thin-section photomicrographs showing three modes of clay occurrence. Clay occurs in (1) thin layers and lenses subparallel to bedding (A, B, C, and D), (2) silty to shaley sands (E), and (3) within sandstone

pores (F). In view F the blue indicates porosity, and the dark patches in some pores and coating some grains (arrows) are interpreted to be kaolinite.



**Figure 22.** SEM photographs showing representative textures of Q, quartz; K, kaolinite; and S, smectite. Views in A, B, C, and D are from sands of the basal upper

Carbonera, whereas views E and F are from the top of the Lower Carbonera/"Mirador" M-1 sand. The arrows in view E point to smectite.

| RESERVOIR PARAMETERS BY ENVIRONMENT |                               |                                |                                 |
|-------------------------------------|-------------------------------|--------------------------------|---------------------------------|
| ENVIRONMENT                         | WEIGHTED AVERAGE POROSITY (1) | WEIGHTED AVERAGE CLAY VOL. (1) | WEIGHTED AVERAGE WATER SAT. (2) |
| CHANNEL                             | 25.7%                         | 6.2%                           | 16.4%                           |
| LOW ENERGY CHANNEL FILL             | 22.5%                         | 19.6%                          | 30.8%                           |
| DISTRIBUTARY MOUTH BAR              | 23.8%                         | 13.1%                          | 27.0%                           |
| UPPER SHOREFACE                     | 23.7%                         | 12.3%                          | 22.9%                           |
| LOWER SHOREFACE                     | 22.3%                         | 21.5%                          | 34.3%                           |

(1) ALL NET SAND                      (2) NET PAY ONLY

**Figure 23.** Reservoir parameters by environment.

the Arauca normal fault near the Arauca River, which forms the Colombian-Venezuelan border. The Arauca fault has vertical displacement varying from 10 to 350 ft (3-107 m).

The sealing nature of the wrench faults has been demonstrated by independent oil-water contacts on opposite sides of the faults as well as interference testing between wells across the Caño Limon fault. The fact that vertical displacement is zero at some points along the faults suggests that the seals are due to shale smear along the fault planes.

Syndepositional fault motion created topographically low areas such as those on either side of the Caño Limon high (Figures 6 and 18), resulting in local thickening of the Lower Carbonera/"Mirador" M1 and M3 zones as well as in the lower part of the upper Carbonera. Uplift of the northeastern Matanegra block occurred during deposition of the Lower Carbonera/"Mirador," with the Matanegra block later subjected to further faulting during deposition of the Upper Carbonera.

### Oil Sources

The oils at Caño Limon are mainly from a marine source with some terrestrial components (Figure 26). The source rocks have not been identified but are presumed to be Cretaceous basinal facies that accumulated in the Cretaceous depocenter located in the position of the present-day Eastern Cordillera. These rocks have been mostly uplifted into the high mountains comprising the Eastern Cordillera or Andes Mountains. Some source rocks may remain in the foredeep at the eastern margin of the Andes. The maturity indicators and burial history plots (Figures 27-28) support that the present-day flank of the Foreland basin in the Caño Limon area is immature. A theoretical section (Figure 29) indicates

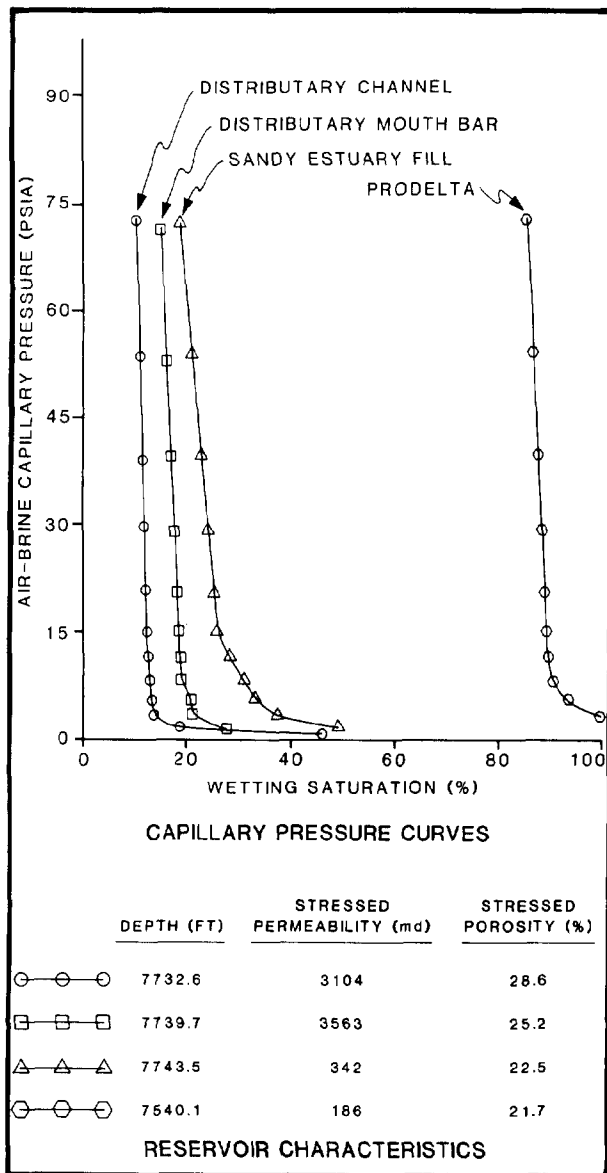
that the source rocks were in the Cretaceous depocenter.

Oil migration distance was on the order of 150 km from the west or northwest. The primary migration conduit is not known but was almost certainly a sandy Cretaceous horizon, possibly as old as the K-3. The oil charge in younger units, including the Lower Carbonera/"Mirador" (the main reservoir) is likely the result of the faults in the area acting as vertical conduits.

Migration probably began in late Oligocene and may have continued into early Miocene. At some point in the Miocene, the generation and migration process was disrupted by the beginning of the Andean orogeny.

### Late Cretaceous Source Rocks

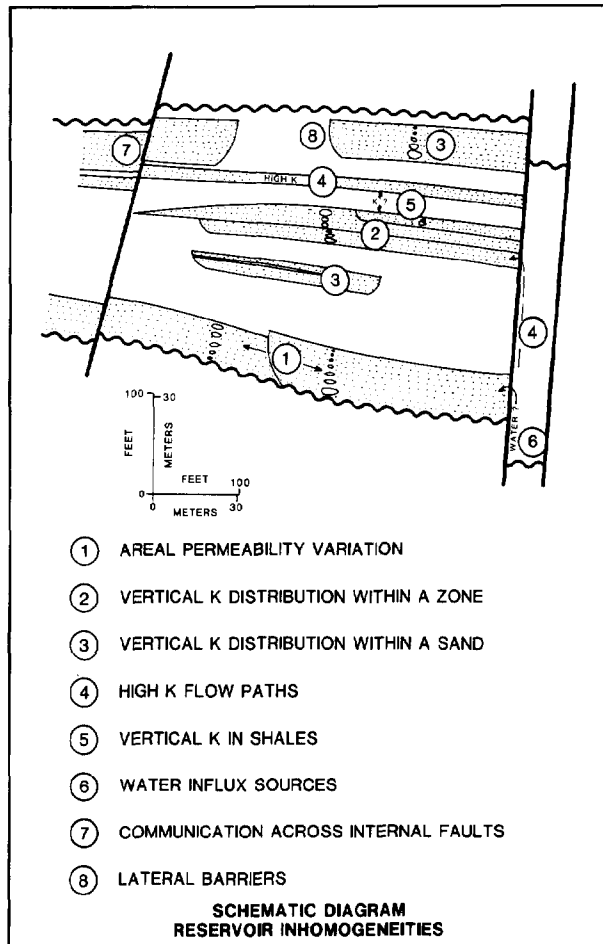
The Late Cretaceous section found in wells of the Llanos foreland basin has a predominantly gas-prone kerogen type. The section in outcrop both in the Eastern Cordillera and its eastern foothills contains more marine oil-prone kerogen that is in some locations waxy owing to a higher content of plant-derived material. Maturity indicators in Caño Limon (Figure 27) show that no mature source is present. In the broader foreland area, the Late Cretaceous is immature to mature (vitrinite reflectance equivalent [VRE] = 0.4-1.0), whereas in Andean outcrops there are sections showing moderate maturity to overmaturity (VRE = 0.8-4.0+). Richness varies from fair (TOC = 0.70) to excellent (TOC = 3.0+). Oil to source rock analysis has shown some affinity of this section to the oil found in Caño Limon but not on a one-to-one correlation. Portions of this section could have entered the oil window during the early Tertiary (Eocene/Oligocene), but it was definitely in the generative stage by the Andean orogeny (Miocene). (See "Theoretical Section," Figure 29).



**Figure 24.** Capillary pressure characteristics and stressed core porosity and permeability of four major reservoir types in the Caño Limon field.

### Early Cretaceous Source Rocks

Little is known about the Early Cretaceous since no wells have penetrated this section. In the eastern foothills and Cordillera, the source type varies from gas prone to oil prone. The section is overmature in all the sampled locations. Richness varies, with total organic carbon (TOC) as high as 4.0. The Early Cretaceous section entered the oil window during the Late Cretaceous or early Tertiary and could have contributed some of the oil found in the Llanos basin. The section probably became overmature as a result of the metamorphism and volcanism associated with the Andean orogeny (Miocene).



**Figure 25.** The types of inhomogeneities and barriers expected to affect fluid flow in the Caño Limon reservoirs.

## EXPLORATION CONCEPTS

### Regional Play

As discussed earlier in the *Pre-Discovery* section, the Oxy Llanos play was based on the following concepts:

1. Generation and migration of oil from Cretaceous source rocks occurred prior to the Andean orogeny of Miocene to Recent.
2. Most of the early-generated oil should have migrated up the easterly flank of the basin to accumulate in early traps, to form a tar or heavy oil belt, or to escape at the surface.
3. Abundant high-permeability sands would allow long-distance migration.
4. A basin as large as the Llanos basin must somewhere have structural or stratigraphic complications to provide hydrocarbon traps.

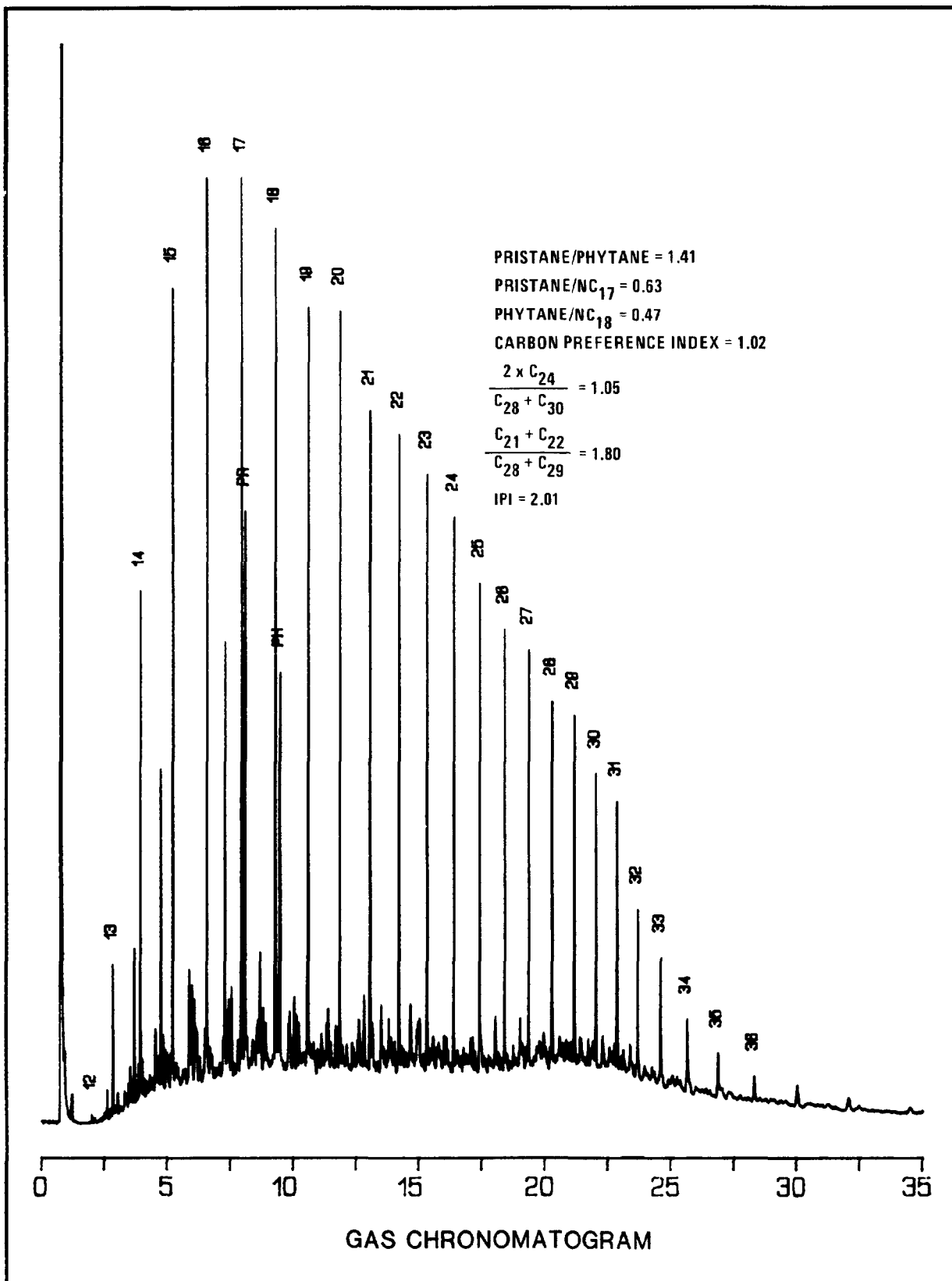
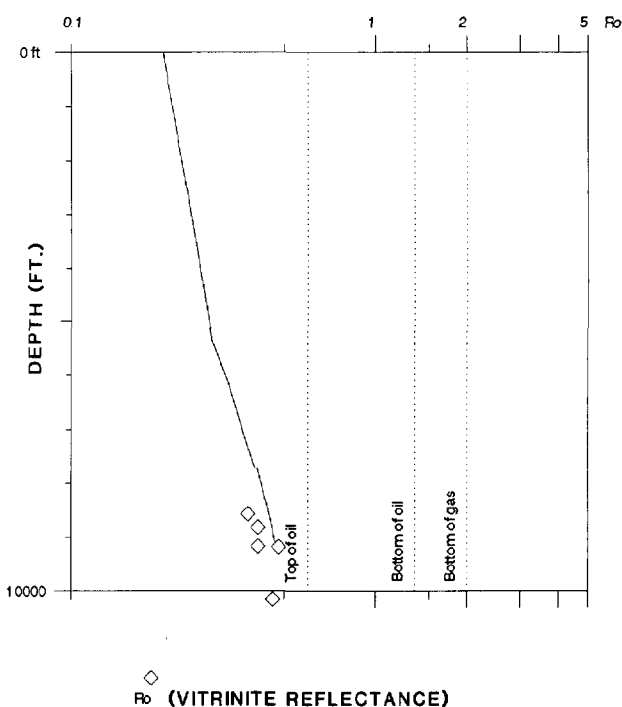


Figure 26. Representative gas chromatogram of C15+ saturate hydrocarbons from Caño Limon oil.



**Figure 27.** Vitrinite reflectance ( $R_o$ ) plot of cutting and core samples analyzed from the Caño Limon-1 well. The value at 9186 ft (2800 m) ( $R_o = 0.48$ ) was measured from a core and is, therefore, more reliable than those measured from the cuttings. The vitrinite reflectance values indicate the section encountered in the field never entered the top of the oil window ( $R_o = 0.65$ ).

5. The Arauca arch could have the necessary structural or stratigraphic complications for oil entrapment.
6. Although not a part of the recommendation for this play, a possible analogy to the Oriente basin of Peru was in some people's minds.

### General Application of Geologic Parameters

The Llanos basin was interpreted to have all the basic requirements for oil except demonstrated traps. The first year seismic survey in the Caño Limon area showed two significant faults with strike-slip characteristics (Figure 5). Based on the premise that such faults could cause associated structural folding, the exploration effort then focused on recording more seismic lines in the area of the faults. The Caño Limon fault/fold structure appears to be related to the convergence of these two faults and the later-identified Matanegra strike-slip fault.

### Lessons

The lessons from the Llanos exploration play are that (1) conventional wisdom about the exploration

potential of an area should not be accepted at face value, (2) perseverance in this kind of frontier exploration is warranted as long as all the essential requirements for oil or gas are likely to be present, and (3) that in virgin areas it is helpful to accept that "anything can happen" and not be constrained by past experience or other "models."

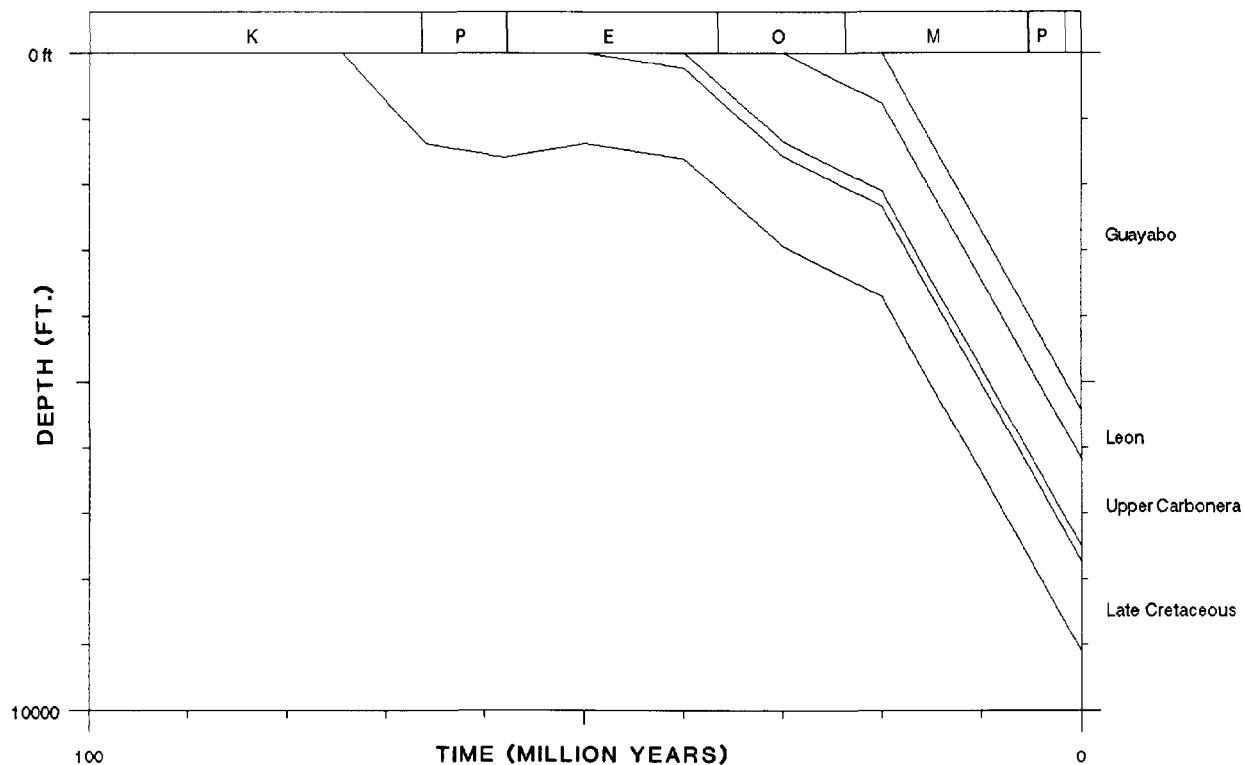
If given the opportunity to do it over again, exactly the same exploration approach would be recommended.

## ACKNOWLEDGMENTS

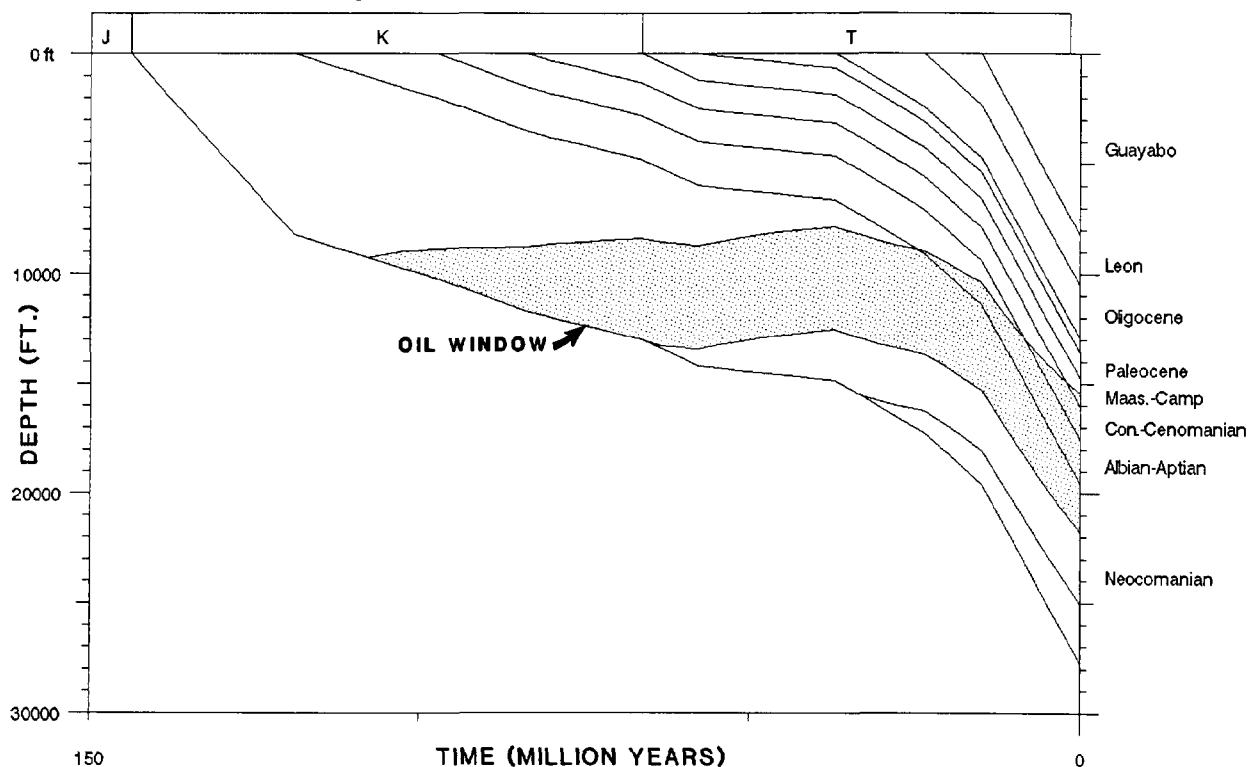
The author wishes to thank Occidental International Exploration and Production Company, as well as partners Ecopetrol, Shell, and Repsol, for permission to submit this Atlas contribution. Thanks also to Oxy associates, Mike Cleveland for the portion on reservoirs description and faults, Judy Russell for help with the geochemistry discussion, and Don Lindsay and Kim Butler for critical review of the text and help with preparation of illustrations. Renae Wilkinson of Platte River Associates, Inc. also deserves thanks for preparation of the burial-history plots.

## REFERENCES

- Cleveland, M. N., 1988, The role of geological core interpretation in reservoir management of Caño Limon field, Colombia: Tercer Congreso Colombiano de Petroleo Memoirs, v. 1, p. 165-182.
- Cleveland, M. N., and J. Molina, in press, Deltaic Caño Limon field, Colombia. Springer-Verlag Sandstone Petroleum Reservoirs.
- Gabela, V. H., 1985, Campo Caño Limon, Llanos orientales de Colombia: II Simposio Bolivariano Memoirs, v. 1, p. 1-29.
- McCullough, C. N., 1988, Geology of the super giant Caño Limon field and the Llanos Basin, Colombia, Transactions: Fourth Circum-Pacific Energy and Mineral Resources Conference.
- McCullough, C. N., and E. P. Padfield, 1985, Petroleum geology of Colombia's Llanos basin: A summary: Oil and Gas Journal, April 15.
- Molina, J., 1988, Condiciones hidrodinamicas de los Llanos septentrionales: Tercer Congreso Colombiano de Petroleo Memoirs, v. 1, p. 183-198.
- Parker, C. A., 1986, Caño Limon reservoir properties suggest high recovery factor: Oil and Gas Journal, May 12, p. 55-58.
- Rivero, Ramon T., J. G. Dominguez, J. A. Slater, and C. L. Hearn, 1988, Caño Limon field, Colombia: the latest giant oil reservoir in South America: Oil and Gas Journal, July, p. 874-880.
- Robertson Research, 1983, The northern Llanos of Colombia, hydrocarbon potential and stratigraphic control, v. 1, 2, and 3.
- Taylor, J. B., 1984, Occidental Caño Limon discovery in the Llanos of Colombia: New Ideas, New Methods, New Developments: Proceedings of the Southwestern Legal Foundation Exploration and Economics of the Petroleum Industry, v. 22, New York, Matthew Nender & Company.
- Tillman, R. W., 1985, Sedimentology and reservoir properties of Occidental de Colombia, Caño Limon No. 3, Llanos basin, Colombia: Technical Report No. 131, p. 65.
- Zambrano, E., E. Vasquez, B. Duval, M. Latreille, and B. Coffinieres, 1971, Paleographic and petroleum accumulation history of western Venezuela, Congreso Geologico Venezolano, v. 1, Memoir 4, Dir. Geol., Bol. Geol., special publication No. 5, p. 483-552.



**Figure 28.** Geohistory plot for the Caño Limon field. Various formation tops encountered in the Caño Limon-1 well are plotted along the right vertical axis of the figure. The time of deposition and burial path through time for each of the formations are shown.



**Figure 29.** Geohistory plot for a theoretical section in the paleodepocenter that is presently uplifted as part of the Eastern Cordillera. Various formation tops assumed present are plotted along the right vertical axis of the figure. The time of deposition and burial path through time for each of the formations are shown. The oil window for these formations is shown by a stippled pattern.

## Appendix 1. Field Description

Field name ..... Caño Limon

Ultimate recoverable reserves ..... 1047 million bbl

**Field location:**

Country ..... Colombia

State ..... Arauca

Basin/Province ..... Llanos basin

**Field discovery:**

Year field discovered ..... 1983

Year second pay discovered ..... 1984

Third pay ..... 1984

**Discovery well name and general location**

(i.e., Jones No. 1, Sec. 2T12NR5E; or Smith No. 1, 5 mi west of Sheridan, Wyoming):

First pay ..... Caño Limon-1 Lower Carbonera/"Mirador" (Mirador sand),  
50 m SW of Aranca in NE Columbia

Second pay ..... La Yuca-1 lower K-1 sand

Third pay ..... Matanegra-1 K-2A sand

Discovery well operator ..... Occidental de Colombia, Inc.

(If more than one pay in field, list operators of discovery well in other pays)

Second pay ..... Occidental de Colombia, Inc.

Third pay ..... Occidental de Colombia, Inc.

**IP in barrels per day and/or cubic feet or cubic meters per day:**

First pay ..... 10,690 BOPD (Caño Limon-1)

Second pay ..... 7995 BOPD (La Yuca-4)

Third pay ..... 10,784 BOPD (Matanegra-8)

**All other zones with shows of oil and gas in the field:**

| Age       | Formation             | Type of Show                |
|-----------|-----------------------|-----------------------------|
| Oligocene | Upper Carbonera Sands | Oil Productive (fourth pay) |

**Geologic concept leading to discovery and method or methods used to delineate prospect, e.g., surface geology, subsurface geology, seeps, magnetic data, gravity data, seismic data, seismic refraction, nontechnical:**

*Based on published regional studies there was the concept that a cross-basinal arch (the Arauca arch) might be present in the largely unexplored Northern Llanos basin. Reflection seismic was used to look for structural or stratigraphic complications associated with the possible arch.*

**Structure:**

Province/basin type (see St. John, Bally, and Klemme, 1984) ..... Foreland basin

**Tectonic history**

*Structurally deformed and rifted Paleozoic sediments were peneplaned to a predominantly Ordovician level with inliers of Triassic redbeds. Cretaceous continental and marine deposits were structurally deformed by strike-slip faulting that continued into Oligocene. The Caño Limon structure resulted from this deformation.*

**Regional structure**

*The field is associated with a system of probably right lateral strike-slip faults on the gently west-dipping east flank of the Llanos basin.*

**Local structure**

*A southwesterly plunging anticlinal nose formed by convergence of three major strike-slip faults with attendant folding.*

**Trap**

**Trap type(s)**

Two main traps formed by folding associated with strike-slip faulting, one trap formed by strike-slip fault convergence, at least two traps resulting from onlap of Oligocene Carbonera onto Eocene structures.

**Basin stratigraphy (major stratigraphic intervals from surface to deepest penetration in field):**

| Age               | Formation                 | Depth to Top in ft |
|-------------------|---------------------------|--------------------|
| Miocene-Recent    | Guayabo                   | 0                  |
| Miocene           | Leon                      | 5460               |
| Oligocene-Miocene | Upper Carbonera           | 6100               |
| Eocene            | Lower Carbonera/"Mirador" | 7600               |
| Cretaceous        | Guadalupe (K-1, K-2, K-3) | 7845, 8145, 8500   |
| Paleozoic         | Paleozoic                 | 9300               |

**Location of well in field**

**Reservoir characteristics:**

Number of reservoirs ..... 4

Formations ..... Upper Carbonera, Lower Carbonera/"Mirador," K-1, K-2A

Ages ..... Oligocene, Eocene, Cretaceous

Depths to tops of reservoirs ..... Upper Carbonera, 7500 ft;  
Lower Carbonera/"Mirador," 7600 ft; K-1, 7845 ft; K-2A, 8145 ft

Gross thickness (top to bottom of producing interval) ..... 700 ft

**Net thickness—total thickness of producing zones**

Average ..... 284 ft

Maximum ..... 353 ft

**Average**

**Maximum**

Lithology ..... Moderately sorted fine to coarse poorly consolidated quartzose sands

Porosity type ..... Intergranular

Average porosity ..... 24.5% (cores)

Average permeability ..... 5322 md (from DSTs)

**Seals:**

**Upper**

Formation, fault, or other feature ..... Various shales

Lithology ..... Shale

**Lateral**

Formation, fault, or other feature ..... Faults, onlap (upper Carbonera)

Lithology ..... NA

**Source:**

Formation and age ..... La Luna or equivalent (Cretaceous)

Lithology ..... Predominantly marine shale

Average total organic carbon (TOC) ..... Unknown

Maximum TOC ..... Unknown

Kerogen type (I, II, or III) ..... I/II (based on oils)

Vitrinite reflectance (maturation) .....  $R_o = 0.8$  (estimated from oils)

Time of hydrocarbon expulsion ..... Early Tertiary (Oligocene-Miocene)

Present depth to top of source ..... 20,000 ft to outcrop in Andes Mtns

Thickness ..... Unknown

Potential yield ..... Unknown

## Appendix 2. Production Data

|                                       |  |
|---------------------------------------|--|
| Field name .....                      | Caño Limon   |
| <b>Field size:</b>                    |  |
| Proved acres .....                    | 8821 ac  |
| Number of wells all years .....       | 52   |
| Current number of wells .....         | 49 producing   |
| Well spacing .....                    | 1 km   |
| Ultimate recoverable .....            | 1047 million bbl   |
| Cumulative production .....           | 234 million bbl  |
| Annual production .....               | 67 million bbl   |
| Present decline rate .....            | 0%   |
| Initial decline rate .....            | 0%   |
| Overall decline rate .....            | 0%   |
| Annual water production .....         | 102 million bbl  |
| In place, total reserves .....        | 1800 million bbl   |
| In place, per acre-foot .....         | Variable   |
| Primary recovery .....                | 1047 million bbl   |
| Secondary recovery .....              | None   |
| Enhanced recovery .....               | None   |
| Cumulative water production .....     | 227 million bbl  |
| <b>Drilling and casing practices:</b> |  |
| Amount of surface casing set .....    | 900 to 2500 ft   |
| Casing program .....                  | 13 $\frac{1}{2}$ -in. at 900-2500 ft; 9 $\frac{1}{2}$ -in. at 8000-8500 ft (production string); 4 $\frac{1}{2}$ -in. tubing (with ESP as water cut increases) set at 1500 ft |
| Drilling mud .....                    | Water base—nondispersed  |
| Bit program .....                     | 17 $\frac{1}{2}$ -in.; 12 $\frac{1}{4}$ -in. soft formation  |
| High pressure zones .....             | None   |
| <b>Completion practices:</b>          |  |
| Interval(s) perforated .....          | As required  |
| Well treatment .....                  | None   |
| <b>Formation evaluation:</b>          |  |
| Logging suites .....                  | DLL-MSFL-SP-GR, LDL-CNL-GR, LSS, RFT, SHDT, EPT optional, SWC, velocity survey   |
| Testing practices .....               | Cased hole testing by zone prior to completion   |
| Mud logging techniques .....          | Standard unit to log lithology and shows   |
| <b>Oil characteristics:</b>           |  |
| Type .....                            | Aromatic intermediate to paraffinic/naphthenic (Tissot and Welte Classification in "Petroleum Formation and Occurrence," 1984, Springer-Verlag, p. 419)                      |
| API gravity .....                     | 29.5°  |
| Base .....                            | 60°F   |
| Initial GOR .....                     | 8 ft <sup>3</sup> /bbl   |
| Sulfur, wt% .....                     | 0.41   |
| Viscosity, SUS .....                  | 4-5 cp at 207°F, 3200 psi  |
| Pour point .....                      | 50°F   |
| Gas-oil distillate .....              | NA   |
| <b>Field characteristics:</b>         |  |
| Average elevation .....               | 450 ft (G.L.)  |

|                                    |   |
|------------------------------------|---|
| <b>Initial pressure</b> .....      | 3213 psia at -7100 ft                   |
| <b>Present pressure</b> .....      | 3100 psi                                |
| <b>Pressure gradient</b> .....     | 0.357 psi/ft                            |
| <b>Temperature</b> .....           | 207°F at -7100 ft                       |
| <b>Geothermal gradient</b> .....   | 1.68°F/ft                               |
| <b>Drive</b> .....                 | Very strong water drive                 |
| <b>Oil column thickness</b> .....  | 700 ft max.                             |
| <b>Oil-water contact</b> .....     | -7284 ft (Mirador) (slightly tilted)    |
| <b>Connate water</b> .....         | 23%                                     |
| <b>Water salinity, TDS</b> .....   | 2000 (oil zones); 280 (aquifers)        |
| <b>Resistivity of water</b> .....  | 1.5 ohm (oil zones); 10 ohms (aquifers) |
| <b>Bulk volume water (%)</b> ..... | 5 (Mirador)                             |

**Transportation method and market for oil and gas:**

*Pipeline (18-24-in.) 478 mi over Andes Mtns (8800 ft max. elev.) to offshore storage (converted tanker) and loading facilities at port of Covenas, Colombia. Shipped mainly to U.S. Gulf Coast.*