COLOMBIA
OIL STUDY

**REGIONAL PETROLEUM GEOCHEMISTRY
OF CRUDE OILS FROM THE LLANOS,
MIDDLE MAGDALENA, UPPER MAGDALENA,
CAUCA PATIA AND PUTUMAYO BASINS**

GEOMARK
RESEARCH, INC.

A PROSPECTUS

EXECUTIVE SUMMARY

GEOMARK RESEARCH has performed a regional assessment of Colombia by geochemically analyzing a suite of 300 crude oils. Samples include an extensive set of 100 oils from the Llanos Basin including Cusiana oils and representative oils from the Lower, Upper and Middle Magdalena, Cauca Patia, and Putumayo Basins in Colombia and the Barinas-Apure Basin in southern Venezuela. A list of the analyzed oils is contained in Table I.

Each oil has been characterized by a detailed analytical program that includes bulk compositional data, quantitative biomarker analysis of terpanes and steranes, and determination of stable carbon isotope composition of saturate and aromatic hydrocarbon fractions. Using data from the oils and cluster and principal component analyses, the following has been accomplished:

- Determine the number of genetically distinct oil families in each producing region, including both Tertiary (terrestrial) and Cretaceous (marine)-derived oils.

- Map the stratigraphic and geographic distribution of the oil families and degree of mixing. Compare families among basins and distinguish basins/areas with single oil families (single sources) from those with multiple oil families (multiple sources).

- Utilize geochemical characteristics of the oil families to deduce their source depositional facies, thermal maturity level, and degree of preservation.

- Determine the most likely source unit(s) in each basin by comparing the distribution of oil families and their inferred source facies with regional stratigraphy, burial history, and available source rock data.

- Estimate migrational directions by comparing oil family and mixing distributions with the location of known depocenters.

- Utilize the geographic, stratigraphic, and structural distribution of source rocks and genetically related oils to identify, map, and rank the petroleum systems in each basin and in the country as a whole.

- Evaluate the effects of secondary oil alterations (migration, biodegradation, etc.) on oil composition, producibility and economic value.

All of the analytical data generated from the oils has been issued in a set of data volumes and on magnetic media. The interpretive report includes full color, wall-size maps showing the distribution of oil families and associated petroleum systems.

The cost of the study is US $42,500.

INTRODUCTION

During the third quarter of 1993 Ecopetrol set in action a strategy to increase exploration investment in Colombia. The three areas specifically targeted include the Llanos, Upper Magdalena, and Putumayo Basins. As a result of this action Colombia has once again become one of the more attractive exploration venues in the western hemisphere, with the first licensing round by competitive tender opening for 90 days on April 18, 1994. Ecopetrol is releasing 14 blocks for bidding in the Llanos Basin and adjoining Llanero foothills of the eastern Cordillera, each averaging about 2100 sq km (Keeley and Arevalo, 1994). Acreage offered in the Upper Magdalena Basin consists of 4,900 sq km, approximately 23% of the total basin area (Maslanyi and Pena, 1994). About 3,500 sq km of acreage is being offered for licensing in the Putumayo Basin (Matthews and Portilla, 1994).

The Llanos Basin, which occupies the northeastern portion of Colombia (Figure 1), is a vast area of grassy lowlands covering an area of about 75,000 sq miles. The basin, which is part of the sub-Andean trend of sedimentary basins that runs the length of the South American continent, is a Paleozoic through Tertiary clastic basin that is bounded by the Guyana Shield on the east and by the Eastern Cordillera on the west. The Llanos and the prolific Middle Magdalena Basins were connected throughout the Cretaceous and Early Tertiary times, a period when the sedimentary intervals of greatest economic interest for hydrocarbon source and reservoir were deposited. The stratigraphic nomenclature and correlation in the Llanos Basin, particularly for the Cretaceous interval, is confusing and somewhat controversial because much of the subsurface information is so remote from the type sections from which many of the formation names and stratigraphic correlations were first derived. The generally accepted source section for the Llanos Basin is the marine shales and carbonates of the Upper Cretaceous Colon and La Luna formations that are roughly correlative basinward to the Upper Cretaceous Guadalupe formation reservoirs. The stratigraphic intervals of greatest economic significance have been the Cretaceous and Lower Tertiary Barcos-Los Cuevos, Mirador, and Carbonera formations. However, new potential in the Llanos Basin has been identified in both deeper higher risk but larger Paleozoic targets and for smaller traps involving proven lower risk plays. To date 51 fields have been found in the Llanos Basin, producing at about 310,000 b/d. This level should rise steeply when Cusiana field is brought fully onstream. Proved reserves now stand at 3.6 billion bbl., yet with an exploration well density of only 1:123,000 acres (1:500 sq km), the Llanos Basin can hardly be considered mature.

The Upper Magdalena Basin is an elongated depression bounded by the Central and Eastern Cordilleras, located in the central part of Colombia (Figure 1). There are two major sub-basins separated by two Pre-Cretaceous highs; the Neiva sub-basin in the south and the Girardot sub-basin in the north. The basin is presently a bivergent foreland basin subsiding under the overthrust load of the Central and Eastern Cordilleras. It has evolved through various tectonic settings including the Triassic-Aptian rift phase, an Aptian-Campanian passive margin phase, and a Campanian-

Recent foreland basin phase. The principal source rock is the La Luna (Villeta) formation, which was deposited during the Late Cretaceous in a partially restricted marine basin. Historical attention has focused on the Cretaceous Caballos and Monserrate sandstones, but new play potential exists for reservoirs in laterally equivalent facies and at other stratigraphic levels. Many volumetrically large structures in the Upper Magdalena Basin remain untested, particularly since potential source rocks are extensively distributed and there are few difficulties with maturation, migration or sealing mechanisms.

The Putumayo Basin, which lies in southern Colombia between the Eastern Cordillera of the Andes and the Guyana-Brazilian Shield (Figure 1), is considered to be the northern extension of the Oriente Basin of Ecuador. The Colombian part extends over an area of 48,000 sq km. The basin evolved through successive rift, passive margin, and foreland basin stages throughout the Mesozoic-Cenozoic. The Villeta formation is the primary source horizon and the Cretaceous Caballos and Villeta sandstones and the Eocene Pepino conglomerates have proven reservoir potential. A recent review of available data suggests that low risk prospects and leads that have proven oil potential, as well as new higher risk, higher return plays remain to be tested in the Putumayo Basin.

METHODOLOGY AND EXPLORATION APPLICATIONS

In areas such as Colombia where substantial production has been established, a regional oil study is an excellent way of identifying, evaluating and comparing the various petroleum systems that have contributed to reserves. A regional oil study approach is particularly useful for comparing the remaining potential of various basins and for predicting the distribution of particular hydrocarbon plays.

The regional petroleum systems within the study area have been evaluated by first determining the number of effective source units within a region by establishing the number of compositionally distinct oil families using multivariate statistical techniques. The source facies of each oil family can be deduced from the oil geochemistry (e.g., Moldowan, *et al*., 1985; Peters, *et al*, 1986; and Zumberge, 1987). A variety of parameters based on molecular and bulk composition can be used to make inferences regarding source lithology, anoxicity, salinity, organic input (marine, non-marine or marginal marine) and thermal maturity. In many cases it is possible to bracket the age of the source from the oil data. Recent studies have shown that multiple oil families exist in the Llanos Basin (Palmer and Russell, 1988) and that the predominant source of oil in the Middle Magdalena Basin are Upper Cretaceous La Luna marlstones (Zumberge, 1984).

The predicted source facies have been compared to the stratigraphy, sedimentology, and burial history of each basin to determine the most probable source units. The aerial extent and burial depth of the source units, combined with the geographic and stratigraphic distributions of their associated oil families and degree of mixing have

been used to determine the location of the various oil generating depocenters and the most probable migration directions.

The relative potential of the petroleum systems in each basin have been ranked by incorporating geological information on source thickness and sedimentary environment, and source potential of the various source units. The results have been evaluated in an effort to identify areas where petroleum systems may exist but have been overlooked or poorly tested.

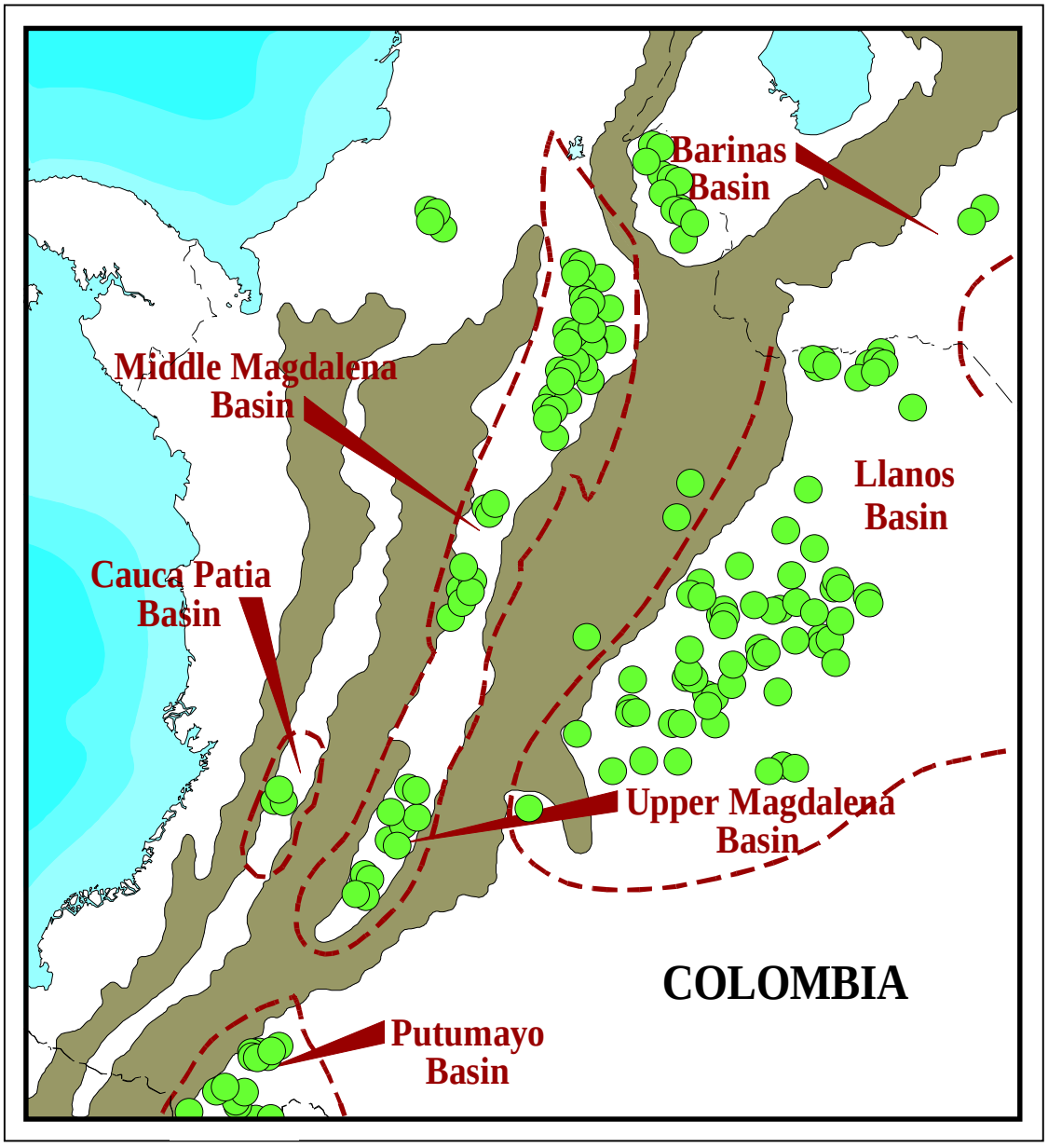

Figure 1. Location Map Showing Distribution of Crude Oil Samples in this Study

ANALYTICAL PROGRAM

The following techniques have been used on each of the oil samples:

- API Gravity
- % Sulfur
- Nickel/Vanadium concentration
- C15+ vs. <C15
- Deasphalting
- Liquid Chromatography (%Sat %Aro %NSO)
- Capillary GC of Whole Crude Oils
- Stable Carbon Isotopes for both Sat and Aro Hydrocarbon Fractions
- GC/MS of branched/cyclic fraction for Terpane/Sterane Distributions

PRESENTATION OF RESULTS

Results of the study are presented in both analytical and interpretive formats to insure that all findings are readily accessible to explorationists and research personnel. All of the analytical data are provided in hard copy and on magnetic media.

Analytical data are presented within **Basin Data Volumes,** and include the following:

- physical property data
- liquid chromatographic data
- gas chromatographic results
- stable carbon isotope data
- GC/MSmass chromatograms.

A synthesis and interpretation of all information is presented in a comprehensive **Final Report**. For each of the basins studied, the **Final Report** includes sections for:

- regional geology,
- inferred oil/source correlations,
- oil generation and migration,
- interpretation of oil characteristics,
- and differentiation of oil families/mixing by multivariate statistics.

PARTICIPATION

The cost of the study is US $42,500. The project is complete and ready for immediate delivery.

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Table I - Crude Oil Samples Analyzed for the Colombia Oil Study

Llanos Basin:

Apiay A-11
Apiay 344
Arauca 1
Arauca 2
Buenos Aires 1
Buenos Aires 1
Cano Duya
Cano Gandul
Cano Garza CG-1
Cano Limon 1
Cano Limon 1
Cano Limon 2
Cano Limon 3
Cano Negra 1
Cano Rondon 1
Cano Verde 1
Carbonera CL2
Centaurio 1
Corazon 3
Corocora
Corocora 1
Corsicor 1
Cravo Sur CS-1
Cravo Sur CS-1
Entrerrios 1
Foraleza 1
Guatiquia 1
Guayuriba
Joropo 1
La Gloria 1
La libertad 1
La yuca 1
La Yuca 1
La Yuca 3
La Yuca 6
Los Teques
Matenegra 1
Matenegra 2
Matenegra 2
Paravare 1
Rancho Hermosa 1
Rancho Hermosa 1
Rancho Quamado 1
Redondo 1
Redondo 1
Cusiana 2A
Cusiana 2A
Sardinas 2
Rubiales 12
Castilla 7
Chichimene 2
Suria
Apiay 11
Guatiquia 1
Baracma
Uribante 1
La Yuca 27
La Yuca 20
Jiba 1
Las Fieras 1
El Miedo EM-1
Tauramena 2
El Miedo 4
Trinidad 2
Trinidad 2
Remache Sur 1
San Joaquin 1
Santiago 1
Santiago 1
Suria 1
Suria 3

Middle Magdalena Basin:

Aguas Claras AC-2
Corazon 4
La Salina B11
La Salina B2U
La Salina B4M
La Tigra 10
Payoa 9U
Payoa 9L
La Cira
Lisama 150
Bonanza
Corazon 3
La Salina LS-8A
La Salina 8B
La Salina B9
La Tigra Seep
Payoa 4U
Payoa 20
Velasquez 20
Corazon 1
Corazon 2
La Salina B6M
La Salina LS2
La Salina B14
Payoa 7U
Payoa 11L
Payoa 21U
Infantes 156

Upper Magdalena Basin:

Bunde 2	Los Mangos 18	Ortega 1
Tello 1	Tolado 4	Palo Grande 9
Dina 1A	San Francisco 8	Santa Clara
Hato Nuevo 1	San Francisco	Tenay 1
Los Angeles 5	Esanaga Seep	Casabe 1

Santander Basin:

Tibu 116	Tibu 49	Petrolea 31
Rio de Oro 44	Rio de Oro	Sardinata Norte 31
Teca 101	Rio Zulia	

Putumayo Basin:

Orito 1	Orito 1	Orito 26
Orito 88	Burdine 4	Linda 1
Linda 1	Mary 1	Miraflor 1
Toroyacu 1	Toroyacu 1	Toroyacu 1
Toroyacu 2	Toroyacu 2	Toroyacu 3
Toroyacu 3	Burdine	Burdine
Linda 3	Mary 2	Mary 2
Miraflor 1	Nancy	

Cauca Patia Basin:

Malacea Creel Seep	Cauca Patia 1	Cauca Patia 2

Venezuelan Oils:

Silvestre	Sinco	Guafita
Tarra	West Tarra	Rosario