Report of the Compilation of the

TECHNICAL FILES
OF THE
NATIONAL HYDROCARBONS AGENCY
2004 – 2007

Compiled by:

Alexander Caneva

According to the Contract 116 – 2008

Bogotá D.C. August – 2009

TABLE OF CONTENTS

FIGURES

TABLES

0. INTRODUCTION

The main objective of this book is to describe, in a synthetic manner, a series of regional studies that have been carried out in different Colombian sedimentary basins. The book develops following a deductive approximation, in order to identify propitious scenarios for the hydrocarbons exploration. In order to perform this, firstly the description of studies based on remote and aerogeophysical methods is introduced. Afterwards, field inspection, based on thematic cartographical studies (e.g. geology and structural sections), is expounded, and, later on, describe studies based on systematic sampling, it means, those studies, which are focused on identification of properties of rocks insitu (e.g. stratigraphy, petrophysics, geochemistry, etc.). Lastly, the book shows studies that are focused on identification of the subsoil's geometry by means of seismic techniques.

The studies have been mostly oriented towards border basins, such as Chocó, Cesar-Ranchería, Guajira, Sinú-San Jacinto, Llower Magdalena Valley, and Eastern Cordillera, where the exploratory history has been limited by infrastructure restrictions, particular social conditions, as well as exploratory prejudices, due to the lack of evidence of any oil system. As it is possible to observe throughout the text, many of the results show new scenarios, with exploratory concepts of an attractive potential, which must be tested. These scenarios generate conceptual changes regarding the development conditions of basins, geometry, types of trapping, presence of generating and reservoir rocks, timing, and available resources.

All of the results and concepts have been developed by well-known consulting companies, national and international universities and institutions, which have consolidated, beyond the specific studies, contexts of revision, reinterpretation of previous studies, and integration of new data, in order to merge new ideas, to confront models, and to debate prejudices. The extensive contents of these studies can be consulted at the Agencia Nacional de Hidrocarburos. Finally, it is a pleasure to express the gratefulness to all authors of the works included in this book; to all of those who took part in the execution and supervision of those works; and to you, dear reader, for making use of them and for your feedback within the exploratory strategy of the Agencia Nacional de Hidrocarburos.

1. CAUCA – PATÍA BASIN

This Cenozoic collision-related basin is bounded to the north and south by basic igneous rocks of the Late Cretaceous Age. Its eastern and western limits are regional tectonic features. The eastern limit is partially defined by the Romeral Fault System, which separate continental crust to the east from oceanic crust to the west (Figure 1).

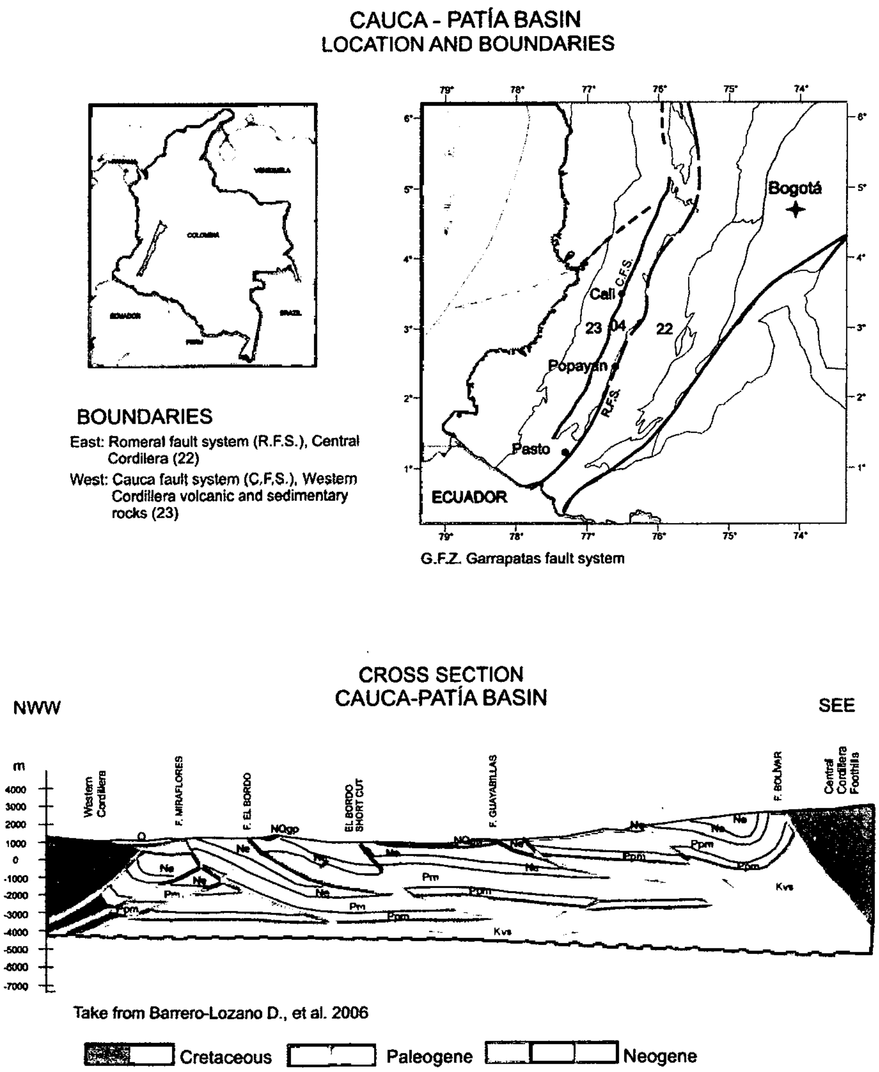


Figure 1. Cauca – Patía Basin.

AIRBORNE GRAVITY AND MAGNETIC SURVEY PROGRAM: ACQUISITION, PROCESSING AND INTERPRETATION OF GRAVITY AND MAGNETIC DATA ON THE VALLE DEL RÍO CAUCA, COLOMBIA[1]

Carson Helicopters, Inc. – Aerogravity Division

www.carsonhelicopters.com

2006

SUMMARY

Carson Aerogravity, a division of Carson Helicopters, Inc. conducted an airborne gravity and magnetic survey of Pacific Littoral, Colombia, for the National Hydrocarbons Agency (Agencia Nacional de Hidrocarburos – ANH). Data from the airborne system are processed for acceleration, speed changes and departures from the flight reference surface made along each individual survey line. A profile is made for each survey line from the following parameters: topography, spring tension in milligals, Eötvös, GPS elevation, GPS PDOP, vertical accelerations calculated from the GPS data, average beam times "K" (i.e., "K" being a constant), and three plots of the free-air gravity with various levels of filtering. This report is intended to present the gravimetric and magnetic data processing and interpretation of the Valle del Río Cauca, Colombia. The entire zone occupied by the gravity and magnetic survey is delimited to the east by the Central Cordillera and to the west by the Western Cordillera.

---

[1] (1) Airborne Gravity and Magnetic Survey – El Valle del Río Cauca, Colombia. Data Procesing Report. June 2006. (2) Levantamiento aerogravimétrico y aeromagnético. Programa adquisición, procesamiento e interpretación de datos de aeromagnetogravimetría en el Valle del Río Cauca. Informe Final de Interpretación. Septiembre, 2006.

The interpretation was focused on the definition of the top of Cretaceous basement, in an effort to define both the location of areas where the biggest thickness of Tertiary sequences may occur, including structural heights where hydrocarbons could be trapped in the sandy facies and in calcareous formations and its structural wedging, while the basement becomes superficial towards the foothill of the Cordillera.

OBJECTIVE

To perform the gravity and magnetic data acquisiton, processing and interpretation on the Valle del Cauca, Colombia. The interpretation was focused on the detection of exploratory objectives associated to Tertiary sedimentary deposits, which could result in a generation, and trapping of hydrocarbons.

GENERAL OUTLINES

Survey Area Description

In 2006 Carson Helicopters Inc. (Aerogravity Division) carried out the acquisition and processing of an airborne gravity and magnetic survey on the Valley of the Cauca River for the National Hydrocarbons Agency (ANH). A DeHavilland twin outer turbo plane performed the acquisition of about 4795 km of gravity and magnetic data respectively, on a 10 km x 5 km flight path. Geophysical data were acquired at an average height of 4750 m above sea level.

Figure 1 depicts the interpretation zone location. The Valley of the Río Cauca Basin is located between latitudes from 02°20'N to 05°10'N and longitude from 75°20'W to 77°20'W.

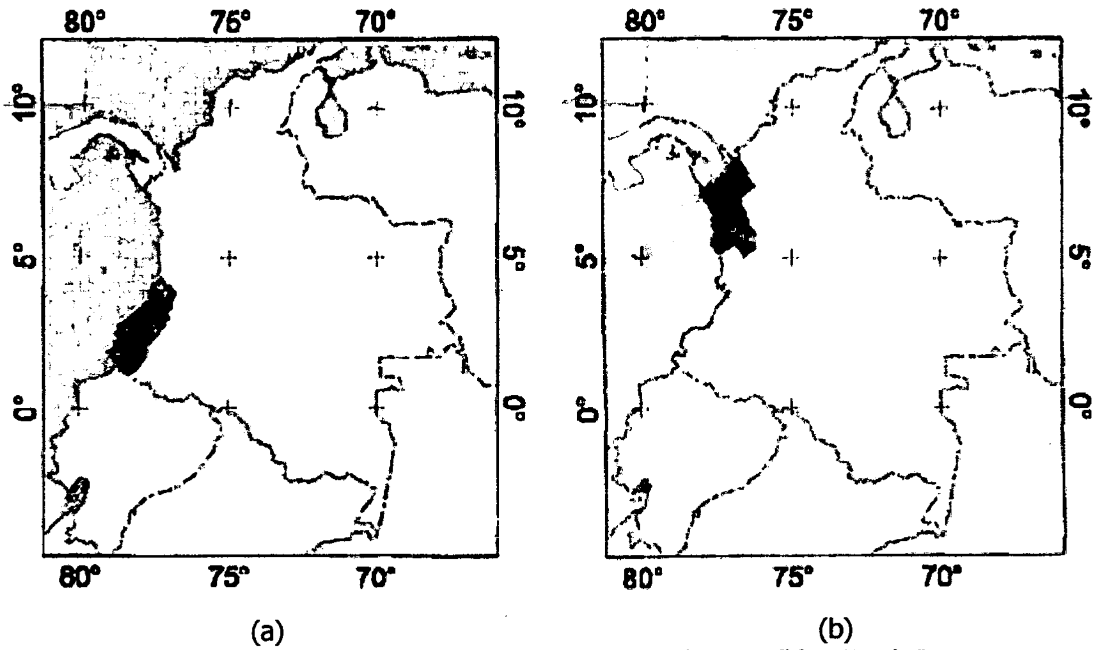


Figure 1. Survey Location Diagram. (a) – South Part; (b) – North Part.

DATA ACQUISITION

Survey System

The airborne gravity and magnetic survey system, outlined below, was developed and patented by Franklin D. Carson and William R. Gumert in 1984 after years of extensive research and field testing. The Valley of the Río Cauca Basin, Colombia survey was performed using a DeHavilland Twin Otter, N920R, and a DeHavilland Twin Otter, N239Z fixed wing aircrafts.

Navigation

Aircraft navigation is maintained through the use of the NAVSTAR Global Positioning System (GPS) and a real-time navigation system. Satellite signals are received by a single antenna contained in the RF unit mounted on top of the aircrafts where they receive the maximum signal strength with minimum interface. The antenna is right-hand circularly polarized, omni-directional in azimuth, and hemispherical in elevation.

Magnetometer

A Geometrics high sensitivity magnetometer was used. This device used a microprocessor unit in order to measure a continuous frequency signal received from one optically pumped Cesium magnetometer sensor mounted within a stinger under the aircraft tail section.

Automatic aeromagnetic digital compensator units are installed in the aircrafts to compensate or correct in real time the magnetic interference caused by the aircraft itself and aircraft maneuvering in the Earth's magnetic field, when using inboard mounted high sensitivity magnetometers. The compensations account for the effects of permanent magnetism, induced magnetism, Eddy currents also remove the heading errors caused by the sensors themselves. It provides a frequency bandwidth of DC to 0.9 Hz, the frequencies of greatest interest to the geophysicist. The signal(s) from the magnetometer(s) is (are) digitized faithfully without aliasing or phase distortion.

The variations of the Earth's magnetic field are recorded during flight in units of one tenth of a nanotesla at ten times per second sample rate on magnetic medium. The magnetic data is also recorded in flight on an analog paper strip chart for direct field monitoring. A magnetic base station, which records diurnal effect, will be set up and operated near the aircraft parking area at the airport used for the survey operations base. The magnetometer and recorder will be set up in a magnetically quiet area near this base and will be in operation during data collection times. These data will be used as a base constant comparison to the acquired flight data.

Altimetry

The Rosemount Model 1201F Pressure Transducer is designed to provide a highly accurate, high level DC output voltage linear with sensed absolute pressure. The excellent linearity of the output allows direct reading or recording of a highly accurate signal without additional correction or amplification. The Model 1201F

Gravity Meter Constant:	0.9979	Milligals per counter unit
Base Gravity:	977.88299	Gals
Base Spring Tension:	9258.0	Counter units
Magnetometer:		
Base Magnetics:	31000	Nanoteslas

DATA INTERPRETATION AND CONCLUSIONS

Sediments deposited in the basin are predominantly low-density clastic sediments (2.1 g/cm^3 to 2.4 g/cm^3). These sediments are over an igneous-metamorphic basement of high-density Cretaceous rock (2.6 g/cm^3 to 2.75 g/cm^3). Based on these values, the density that was used to transform the free-air anomaly into Bouguer Anomaly was 2.30 g/cm^3.

All maps in this Project were prepared using the GEOSOFT graphic system with final grids of 1000 m.

Bouguer Anomaly and Magnetic Intensity

Figure 2 shows the Bouguer Anomaly map with a density of 2.30 g/cm^3.

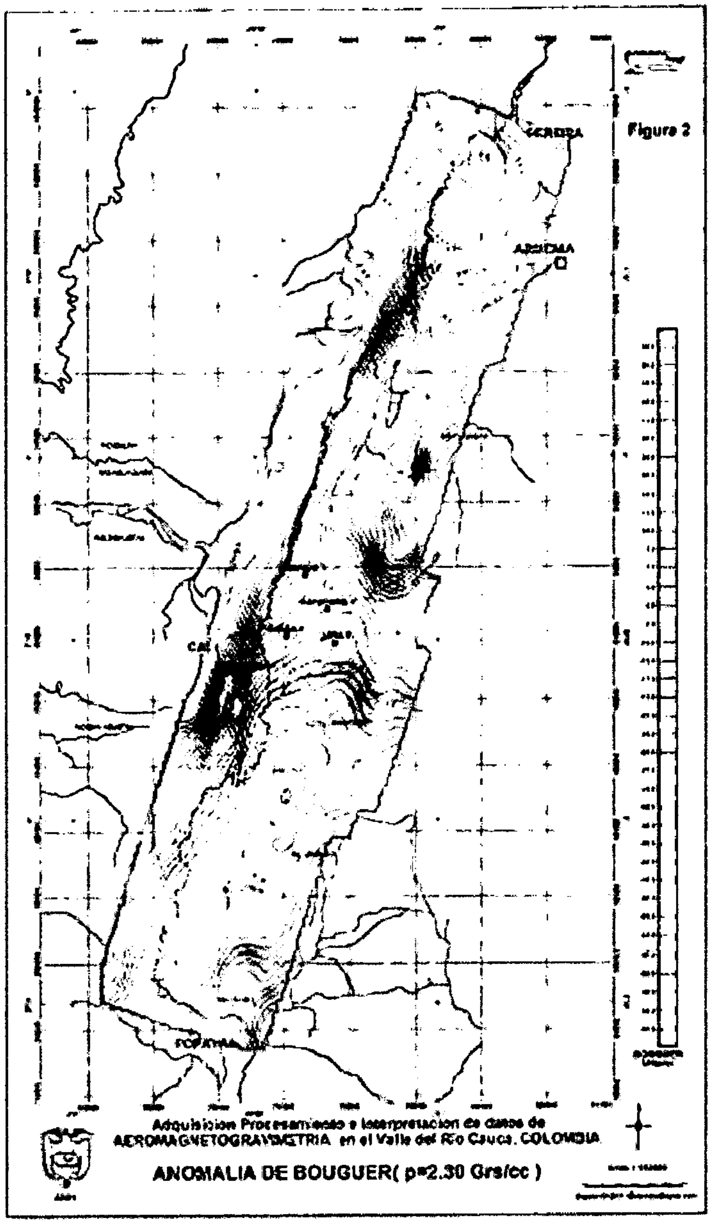


Figure 2. Bouguer Anomaly map with a density of 2.30 g/cm^3.

The Bouguer Anomaly was correlated with the contrast of density, which exists among the Tertiary sequences and the Cretaceous Basement. This contrast of an approximate value -0.25 g/cm^3 dominates the map of Bouguer to a large extent.

The Valley of the Cauca River shows negative Bouguer anomalies in the farthest north and south of the study area. These negative anomalies indicate where the biggest thickness occurs in the Quaternary-Tertiary sequences. The positive anomalies of great length along the western line could be understood as Cretaceous. In the farthest southestern survey we can see a negative anomaly with values lower than -120 mgal. This anomaly is related to the root of the Central Cordillera and does not indicate the presence of a sedimentary basin.

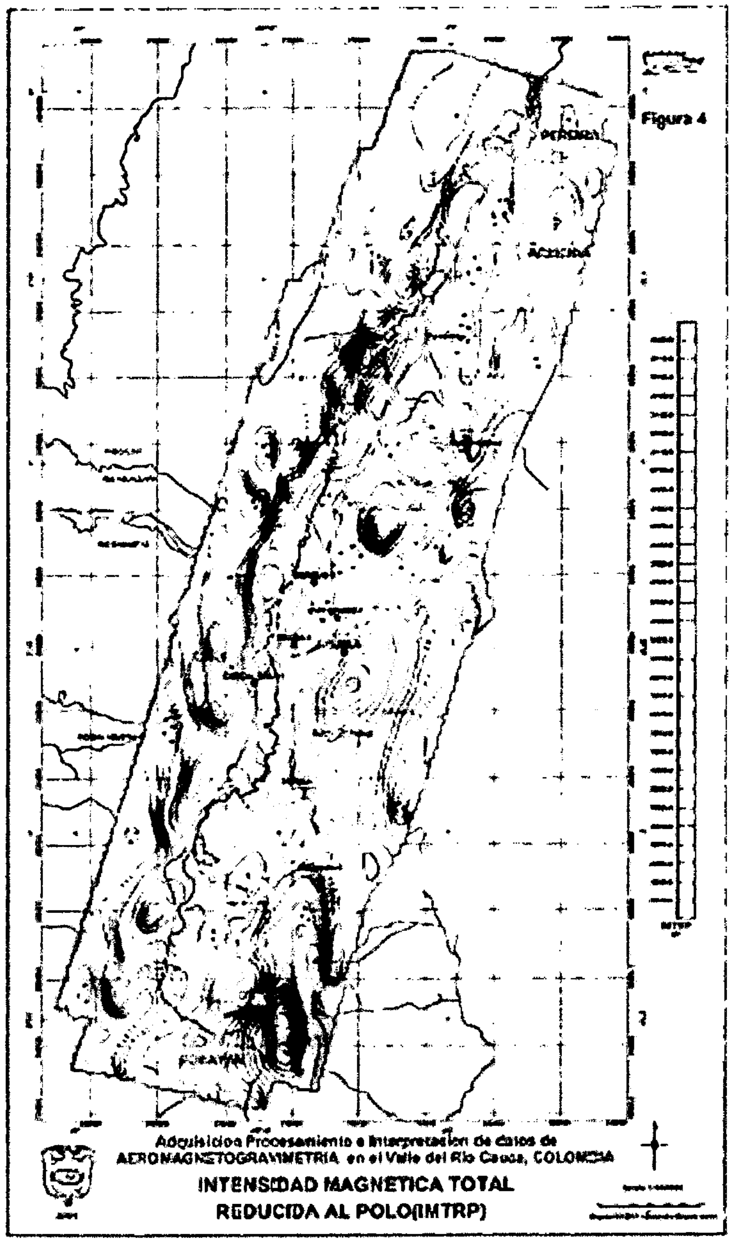


Figure 3. Total Magnetic Intensity Reduced to the Pole (TMIRP).

Figure 3 shows the Total Magnetic Intensity Reduced to the Pole (TMIRP). The TMIRP map shows a strong correlation with the Bouguer Anomaly but with a much higher frequency content. Positive anomalies could correspond to the igneous-metamorphic units of the Cretaceous basement rocks.

Analyzing the maps of Bouguer and the Total Magnetic Intensity Reduced to the Pole (TMIRP) and comparing their anomalies with the geological characteristcs of the studied area, it is possible to infer that there is a component of contrasts for magnetic density and susceptibility among the Tertiary and Quaternary sedimentary units against a basement of a complex composition of Cretaceous age. Any residual will always show contributions of basement. In order to avoid this problem and to estimate the gravimetric and magnetic contribution produced just by the Tertiary and Quaternary sequences, there was made a regional-residual separation with geological control. In other words, we have obtained "residual" maps that are not affected by gravitational and/or magnetic effects from sources that are below the discontinuity of density and indicated magnetic susceptibility, that is to say, the top of basement. These maps show only the contribution of the sedimentary cover that is over this horizon.

Figure 4 corresponds to 3D inversion of controlled residuals by deducting the flight height. It represents the top of the Cretaceous basement referred to average level of sea, and finally Figure 5 shows the structural interpretation of the Cretaceous basement that is obtained from Figure 4.

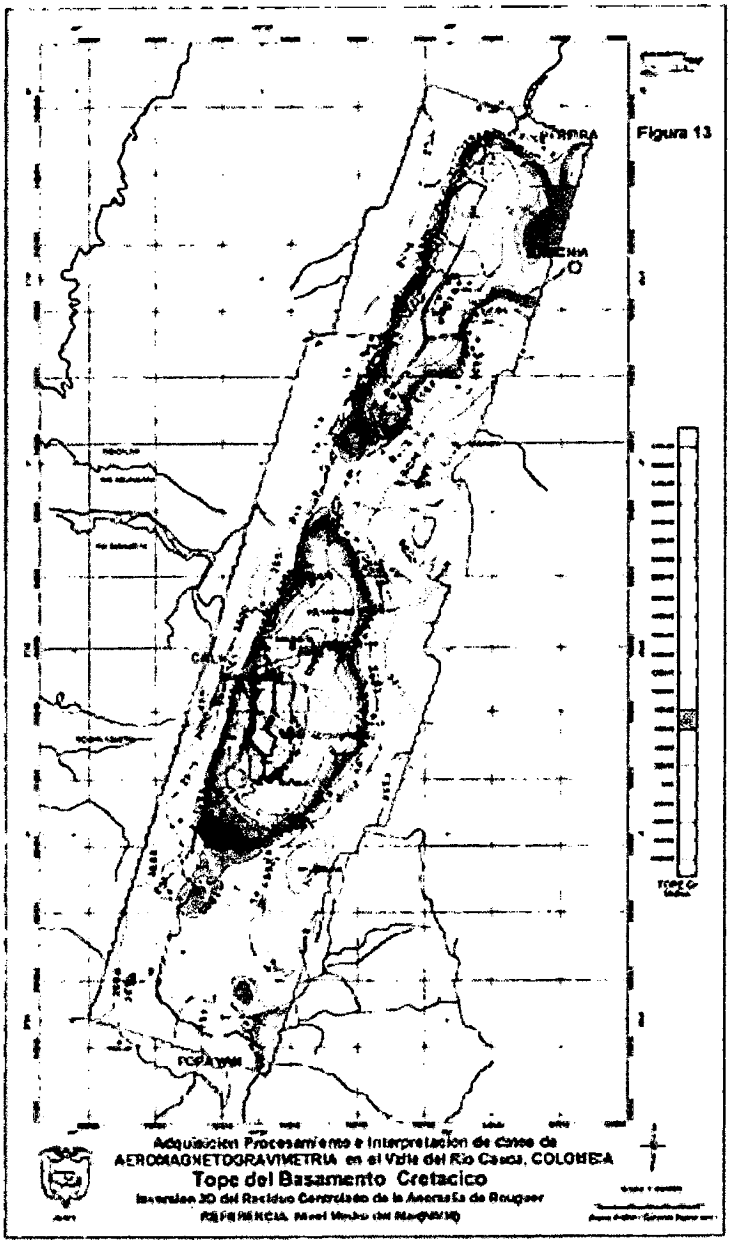


Figure 4. Top of Cetaceous basement referred to average level of sea.

Map of the Structural Interpretation

The map of structural contours from the 3D gravimetric inversion of the residual with geological control, constituted the basis to carry out the structural interpretation of the Cretaceous basement.

In these maps we observe not only where the greatest thicknesses of the Tertiary, Quaternary and Cretaceous sequences occur, but also the interpretation of the main faults and structural characters. The structure is controlled by the Cauca-Almaguer Fault in the east border, which exposes the Paleozic rocks to the surface and places them in contact with younger sediments. The structural map of the base of Tertiary shows structural complexity of the top of the Cretaceous basement and how it comes to the surface at both sides and all along the Cauca River Valley, as well as in the central part of the blown area in the north and northeast of Juda-1, Patacoré-1 and Berejú-1 wells. The greatest thicknesses of the Quaternary-Tertiary sequences occur south of Candelaria-1 Well and southwest of Armenia municipality, where values from the middle sea level to the top of Cretaceous basement (3000 m and 1500 m respectively) were interpreted. Even in this interpretation, it is possible to conclude that there are no thicknesses of Tertiary sequences enough for the generation of hydrocarbons. If migration from other generating sources has occurred to the valley, the best possibilities are associated with structural wedging against the outcroping Cretaceous Basement. The structural map of the possible base of metasedimentary Cretaceous sequences shows a structural distribution quite similar to its top; nevertheless, using the concept detailed by the ANH whith interpreting thicknesses greater than 5000 m referred to the middle sea level, both at south and north of Cali City, it is possible that generating Cretaceous metasedimentary sequences exist.

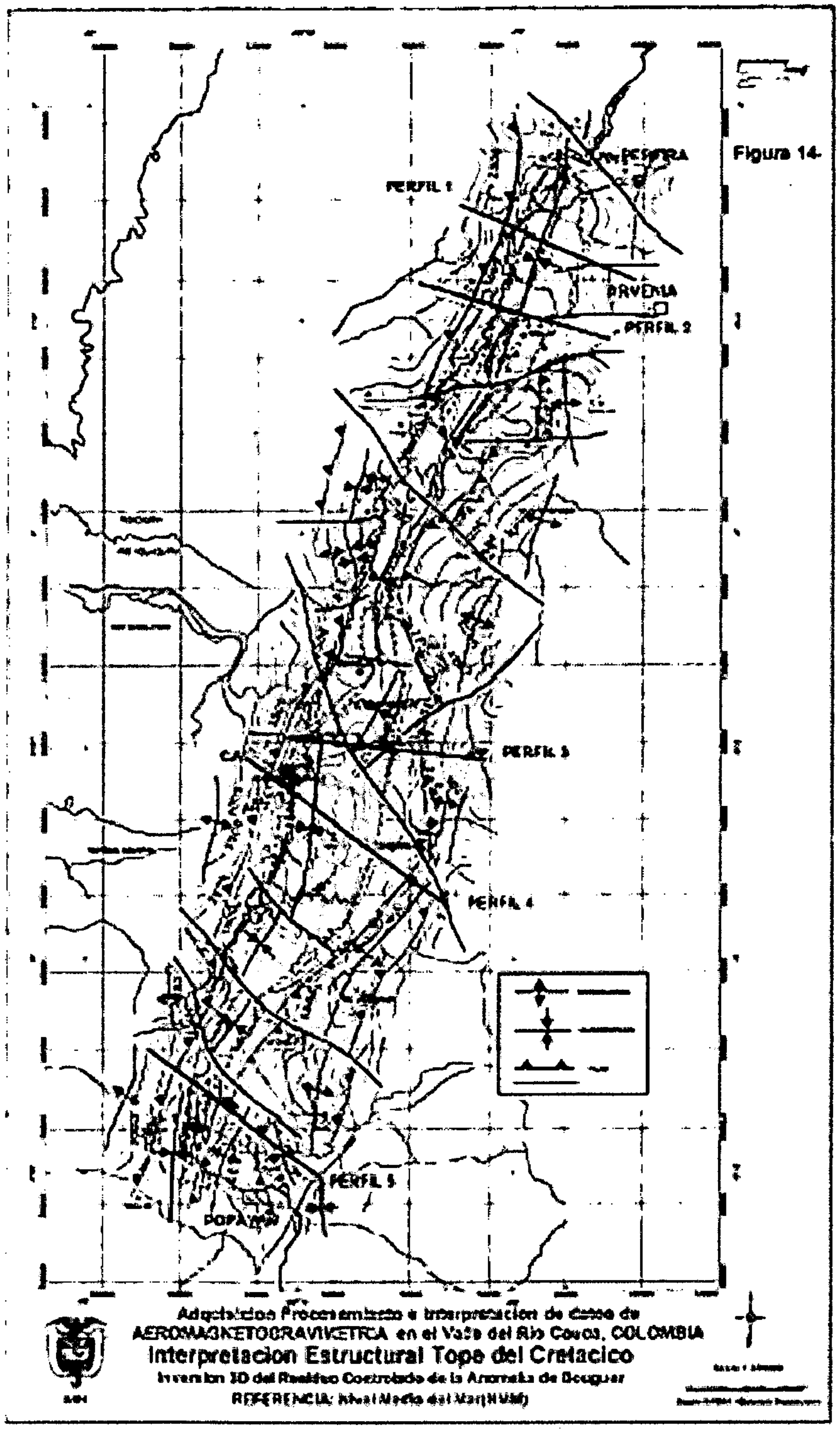


Figure 5. Structural interpretation of the Cretaceous basement.

REFERENCES CITED IN THE ORIGINAL WORK

ANH Registros de Pozos e Información Regional de la Cuenca del Río Cauca. Base de Datos de la ANH.

ANH Mapa Geológico de Colombia. Ariana Ltd. (2004). Diaz L. y Ramos B.

Acosta, J., Lonergan, L. and Coward, M.P. (2004). Oblique transpression in the western thrust front of the Colombian Eastern Cordillera, Journal of South American Earth Sciences, v 17, pp. 181-194.

Barrero D. (1979). Geology of the Central Western Cordillera, west of Buga and Roldanillo, Colombia. Special Geologic Publications of INGEOMINAS. No 4. 1-75 p.

Bermúdez, A. (1996). Transecta geofísica entre la Virginia y Tadó y su tectónica. Memorias del VII Congreso Colombiano de Geología, INGEOMINAS. Tomo III, pp. 68 - 78.

Duque-Caro, H. (1990). The Choco block in the north western corner of South America: Structural, tectonostratigraphic and paleogeographic implications. Journal of South American Earth Sciences, Vol. 3, No 1. pp. 71- 84.

Graterol, V. (2006). Informes Finales de la Interpretación Gravimétrica y Magnética de las Cuencas de Yari-Caguán, Río Cauca y Litoral Caribe Colombiano.

Meschede, M. and Barckhausen, U. (2000). Plate tectonic evolution of the Cocos-Nazca spreading center. *In* Silver, E.A., Kimura, G., and Shipley, T.H. (Eds.), *Proc.*

Moreno-Sanchez, M. and Pardo-Trujillo, A. (2003). Stratigraphical and sedimentological constrains on Western Colombia: Implications on the Evolution of the Caribbean Plate. In Bartolini, C., Buffle, R. and Blickwede (Eds.), The Circum-Gulf of Mexico and the Caribean: Hydrocarbon Habitats, Basin Formation, and Plate Tectonics,AAPG Memoir N° 79, Chapter 40.

Nivia, A. (1996). El complejo estructural Dagua, registro de deformación de la Provincia Litosférica Oceánica Cretácica Occidental. Memorias VII Congreso Colombiano de Geología, Tomo III, pp. 108 - 123.

GEOCHEMICAL SURFACE SURVEY: CAUCA-PATÍA BASIN, SOUTHERN BLOCK[1]

HIDROGEOLOGÍA, GEOLOGÍA, AMBIENTAL LTDA – HGA LTDA.

2006

INTRODUCTION

The sampling of canned gas in free space is one way of analyzing volatile compounds linked to a sample without the use of extraction by solvents. The term "headspace" refers to the free space between the upper part of the liquid or solid content and the lid of a tin can. This technique is usually referred in the pharmaceutical ambit as headspace gas chromatography, and the objective is to analyze the vapor of the substance present in the space between the level of the liquid (or solid) and the lid of a tin can.

OBJECTIVE

Acquisition of 1400 soil samples and processing by headspace gas chromatographic analysis with the purpose of detecting and quantifying existing light gases.

LOCATION

The sampling area is located south of the Cauca Department and north of the Nariño Department (Figure 1) and is surrounded within the polygon with the following coordinates (origin Bogotá) (Table 1).

[1] Estudio geoquímico de superficie. Bloque Sur. Cuenca Cauca-Patía. HGA Ltda. Julio, 2006.

Table 1. Coordinates of the polygon of the sampling area.

Vertex	East (m)	North (m)
P1	672000	734000
P2	650000	720000
P3	622000	663000
P4	658000	643000
P5	672000	655000
P6	680000	672000
P7	687000	696000
P8	700000	720000

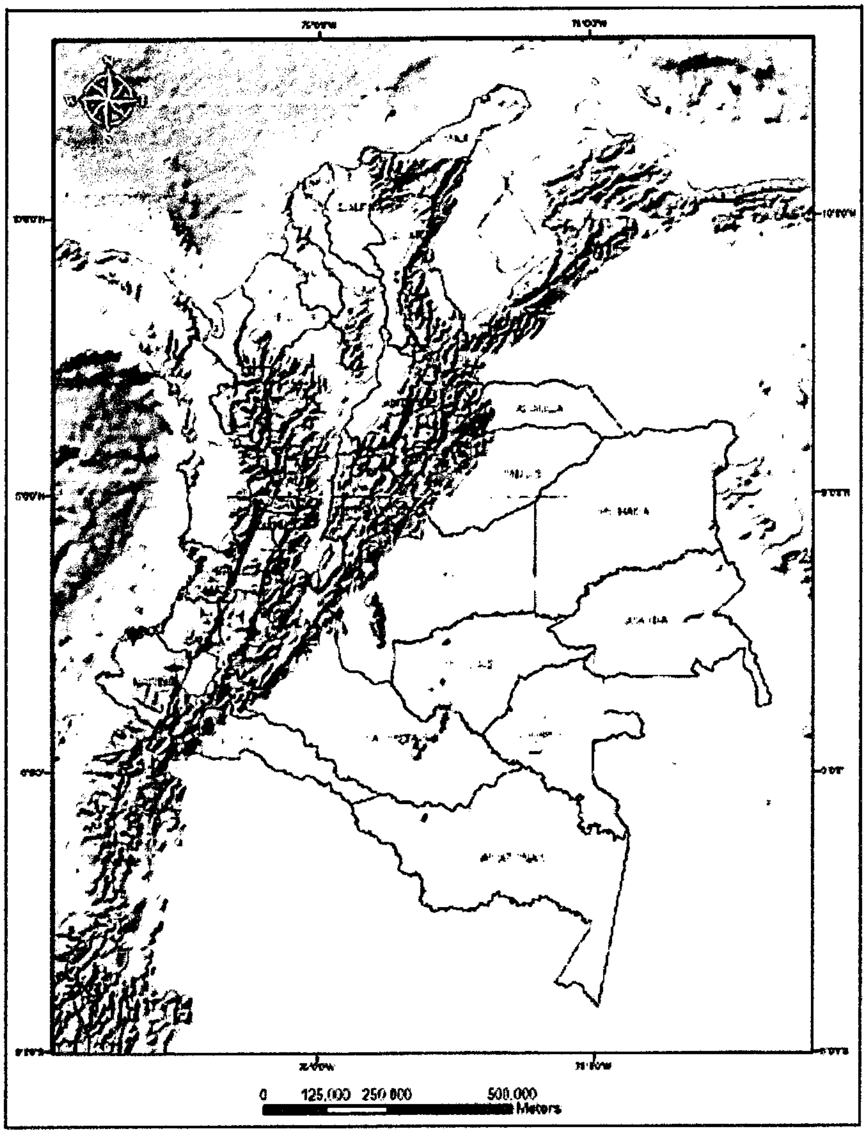


Figure 1. Location of the study area in Colombia.

METHODOLOGY

The steps followed during the acquisition, processing and interpretation of geochemical data are presented as follows:

1) Sampling

- The process was started from a sampling grid designed based on previous geological studies, which define structural characteristics having possible exploratory interest. This grid includes 33 sampling lines: 29 of E-W direction, perpendicular to the main faults, and 3 N-S direction. The distance between the sampling lines is approximately 2 km and between the sampling points, at each line, is 500 m.
- From this grid, knowing the location of the sampling points, sampling points were consecutively enumerated, naming the first point CP-1, and the last one CP-1400. Later on, the Bogotá origin coordinates of each point were read. A list of coordinates was generated. It was used later on, when each GPS was loated daily, according to the points assigned to each geologist for field sampling.
- Before starting the sampling, a stage of area recognition was carried out with the purpose of designing the sampling strategy according to the accesses. This was done in order to obtain the corresponding permits to have access to the properties involved in the sampling, to hire auxiliary personnel and vehicles and to choose the base sites.
- A manual auger was used for the drilling of holes, which have depth between 0.80 and 1.50 m and are approximately 15 cm in diameter. The end depth of the hole is determined by getting to the fresh soil layer, which allows taking the no-contaminated sample, such as possible organic matter from the upper part.
- At each sampling point, approximately 250 g of soil was gathered and put into a tin can with a perforated lid. Before closing the tin can, the sample was diluted in water, filtered and preserved by way of a bactericide in order to avoid

microbial degrading of the gases. With the same characteristics, an additional sample or safety countersample was taken, in case it would be needed to repeat the analysis or for an additional special analyses.

2) Data processing

- Chromatographic analysis of 1400 samples of gas obtained from soil samples.
- Determination of the composition of these gases and quantifying their concentration.
- Determination of the genesis of methane through analysis of carbon isotopes.

3) Interpretation

- Revision of results on the data table.
- Determination of Bernard's humectation index, and estimation of the type of hydrocarbon (biogenetic/mixture or thermogenetic).
- Filtering of database.
- Statistical treatment.
- Determining of the depth constant and of first and second order anomalous values for each one of the gasses (C1 to C5).
- C1, C2, C3, iC4, nC4, iC5 and C5 gas cartography and overlying of C2-C5 gasses.
- Evaluation of chromatographic profiles.
- Cartography and description of areas of interest.
- Determining and plotting of relations.

RESULTS

Chromatographic analysis

For this analysis, a Hewlett Packard series 5890 II chromatograph was used, equipped with a flame ionization detector (FID) and one PLOT capillary column, having a stationary stage of alumina of 50 m length and a 0.53 mm inside diameter.

The *ChemStation* program receives and integrates the signal sent from the gas chromatograph, identifies and quantifies the concentration and shows a graphic representation of the results (chromatogram). The light hydrocarbons in the sample (methane, ethane, propane, acetylene, isobutane, butane, isopentane, pentane and hexane) were quantified according to a certified standard. The equipment was calibrated every 15 samples, and a blank sample was run every 10 analyses. The data obtained from the chromatographic analysis were organized in tables, which were used for chromatographic profiles and interpretation. The interpretation took into account the following:

Determining of the background constant and anomalies was carried out based on statistical treatment. The obtained values are shown on Table 2.

Table 2. Values of anomalies.

Gas	Mean	Standard Deviation	2nd order Anomaly	1st order Gas anomaly
	μ	σ	$\mu + 2\sigma$	$\mu + 3\sigma$
Methane	25.78	41.70	109	150
Ethane	2.25	3.21	8.67	11.88
Propane	0.79	1.18	3.16	4.35
Acetylene	0.08	0.21	0.51	0.72
Isobutane	0.17	0.93	2.02	2.95
Butane	0.46	0.68	1.81	2.49
Isopentane	0.10	0.17	0.44	0.61
Pentane	0.24	0.27	0.79	1.06
Hexane	0.10	0.19	0.49	0.68

Once the background constant and the grade of the first and second order anomalies were defined, contour and classes maps for all the thermogenetic gasses were elaborated. Figures 2, 3 and 4 show examples of the obtained maps:

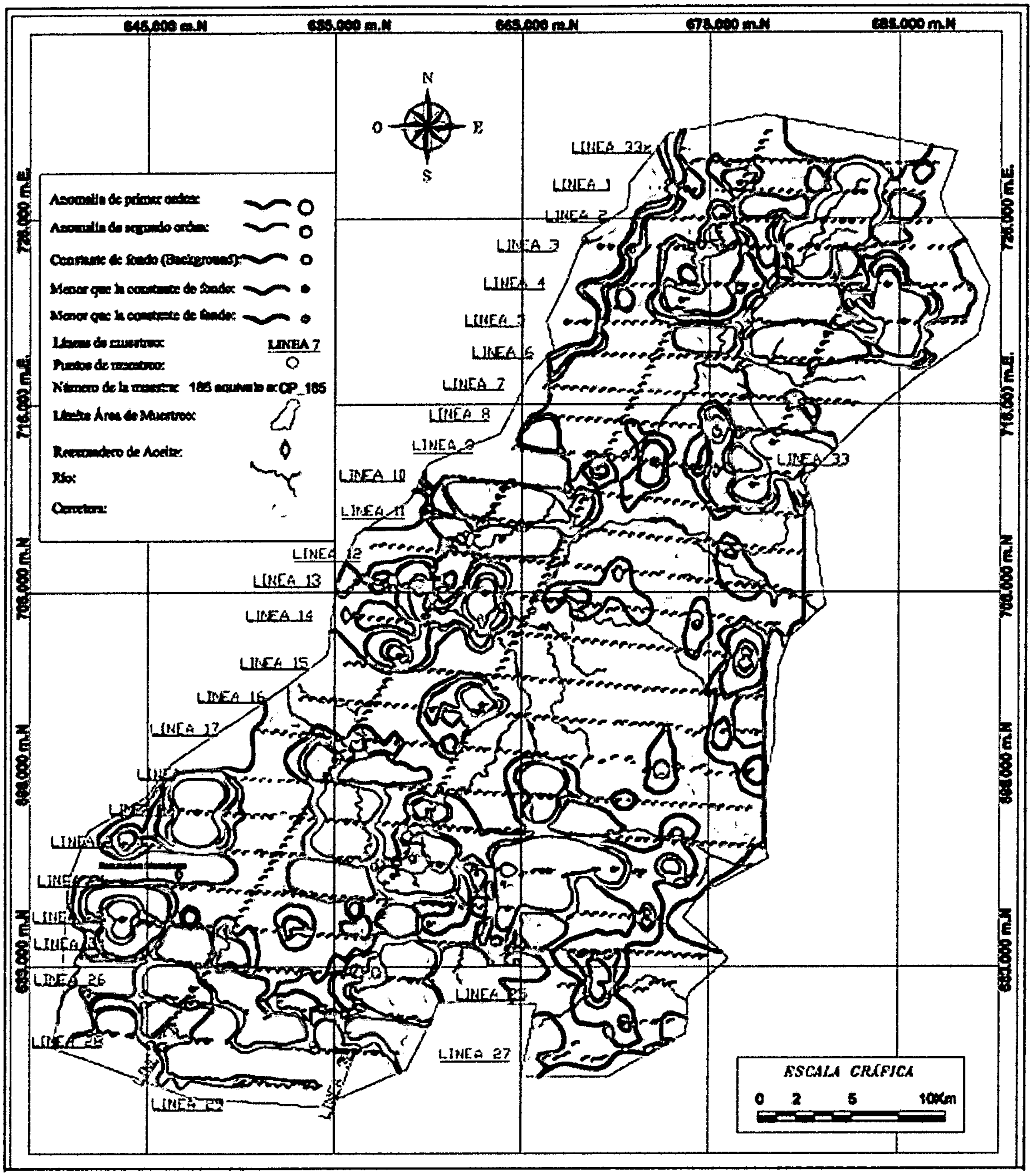


Figure 2. Map of clasess and contours of metane.

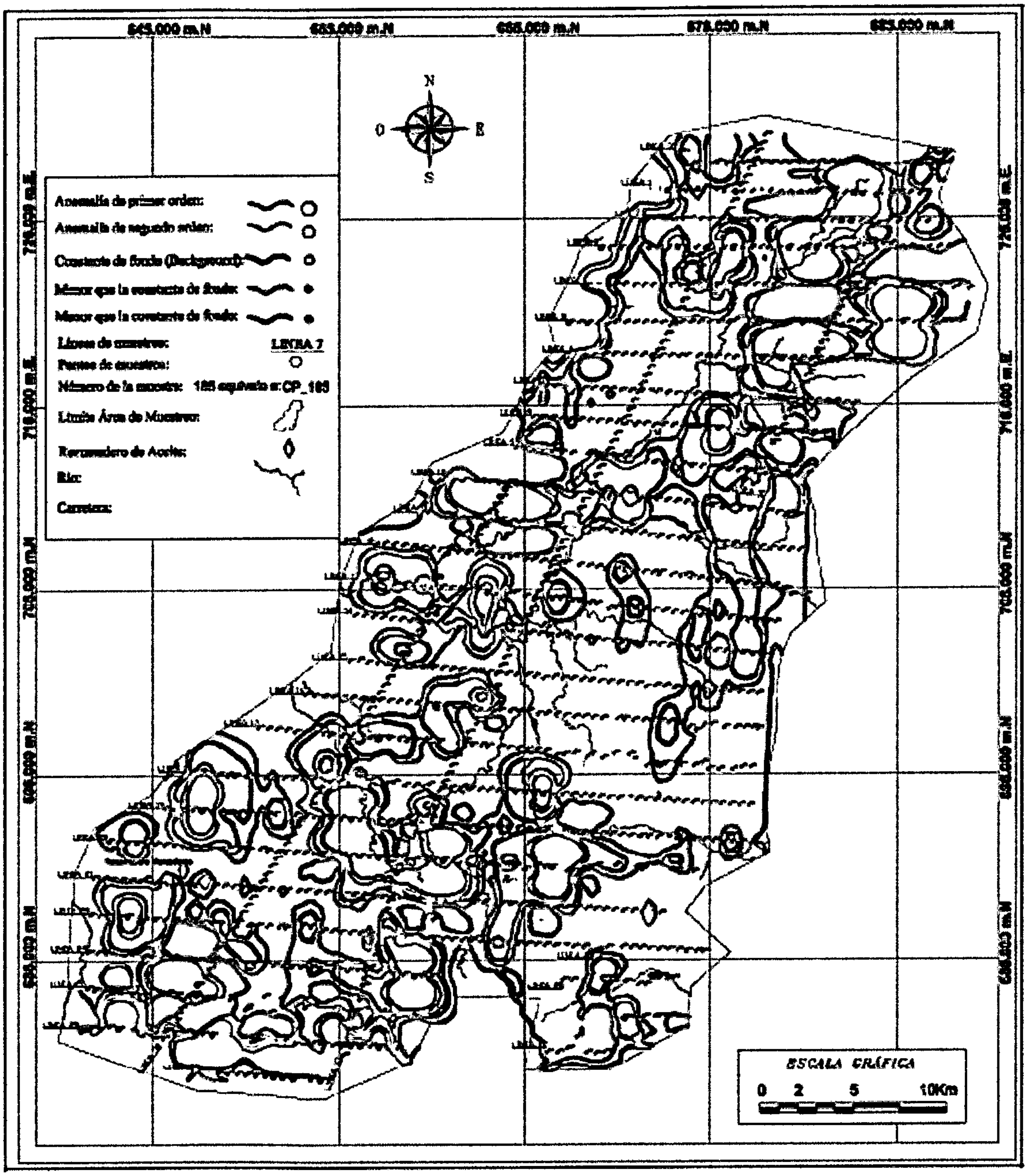


Figure 3. Map of clasess and contours of ethane.

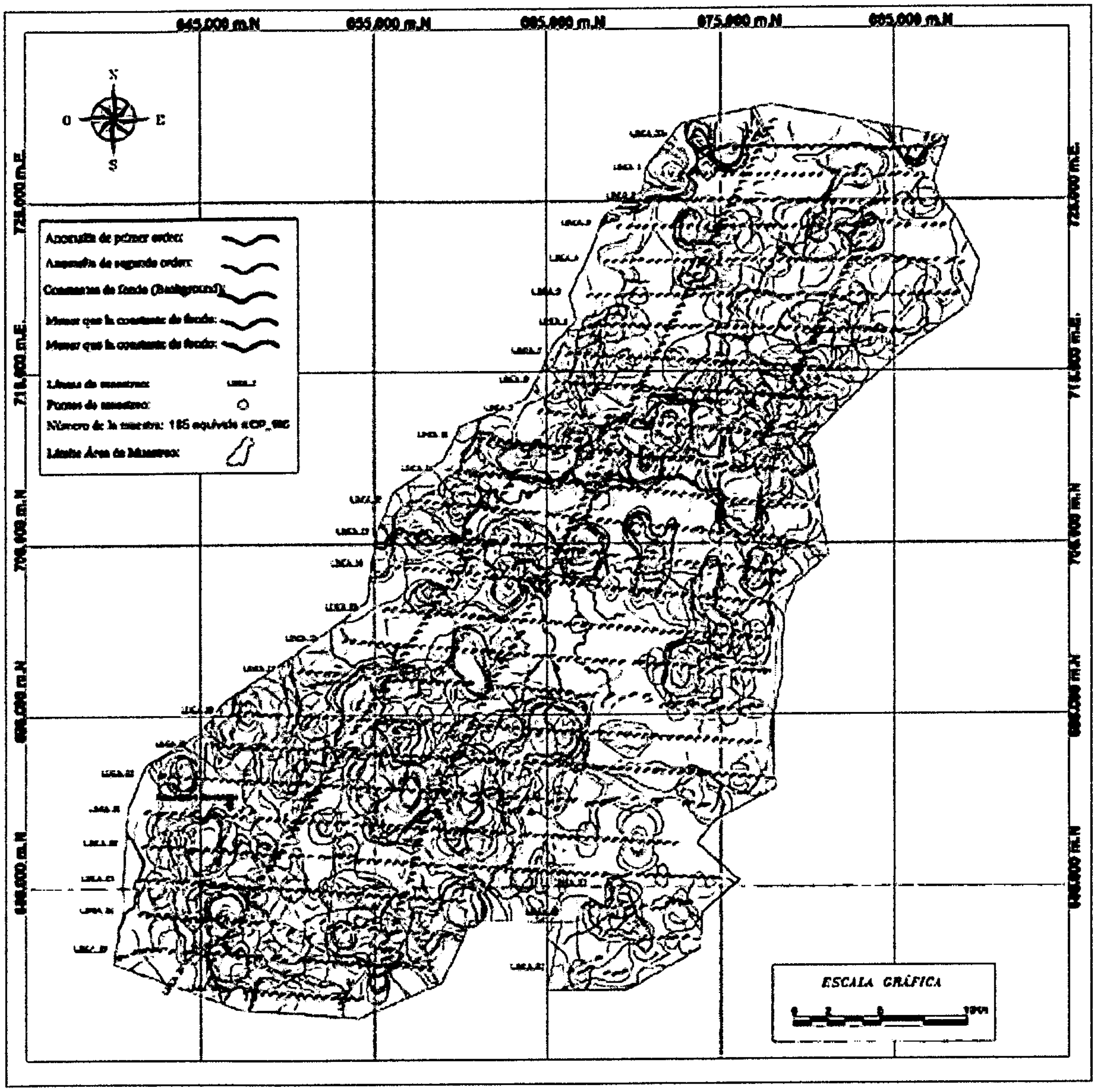


Figure 4. Map of supeposition of C2 to C5 contours.

The interpretation of the chromatographic data of the soil gas samples, evaluated in the present study, allows identification of 13 areas with anomalies of gasses, mainly of methane and ethane (Figure 5).

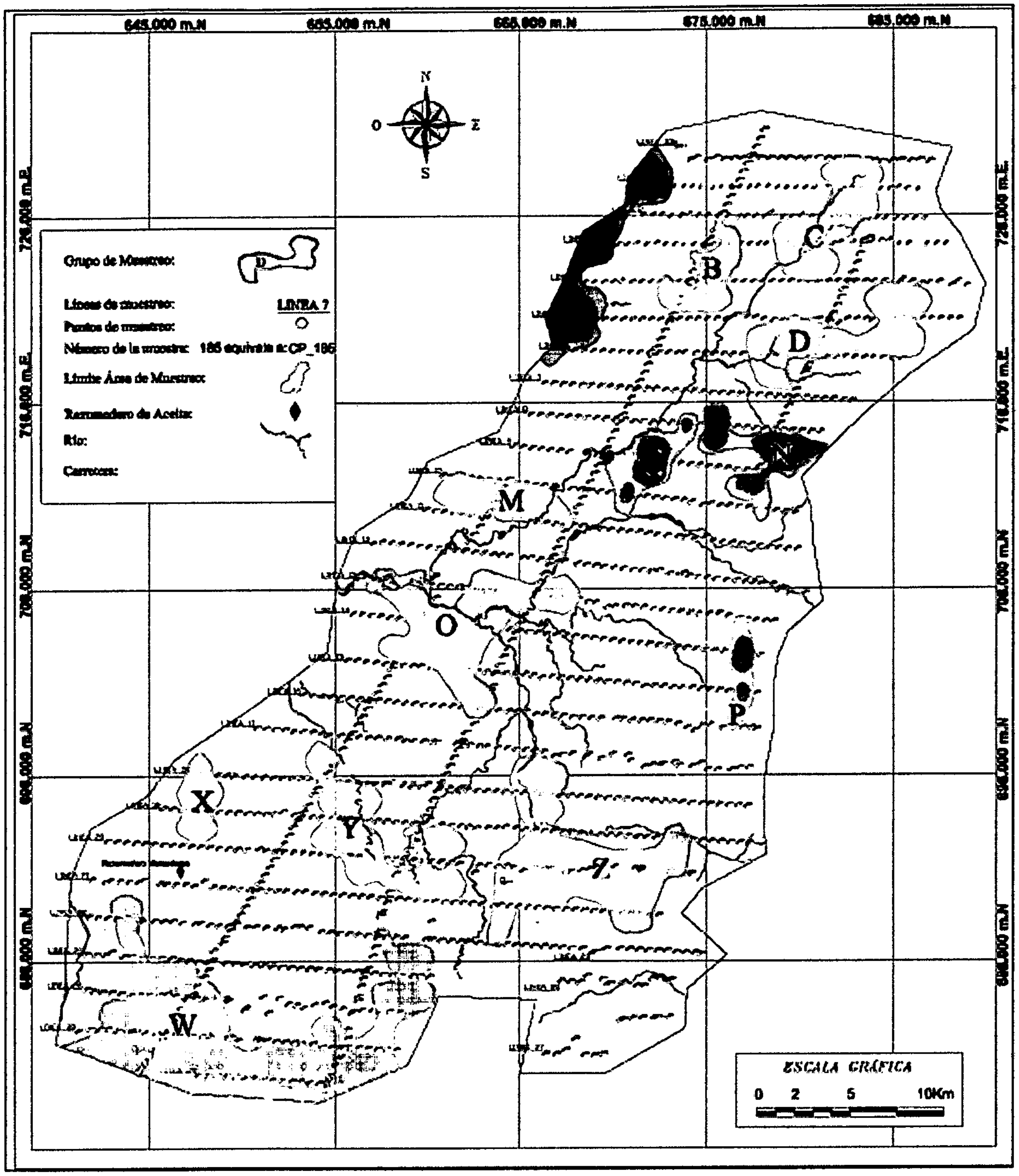


Figure 5. Map of areas of interest

Hydrocarbons Origin

According to Whiticar (1994), the relative proportion of C1-C4 saturated alkanes within a gas sample provides an initial classification of the origin of gas. Bernard (1978), uses the C1/(C2 + C3) ratio for describing the humectation ratio, amongst others, of the surface emanation gasses and sediments and for estimation of their origin (Table 2).

Table 2. Ratio. Bernard's parameter.

Ratio (Barnard's Parameter)	ORIGIN			
	Biogenetic	**Mixture**	**Diagenetic**	**Thermogenetic**
C1/(C2+C3)	>1000	100 - 1000	50 - 100	0 – 50

By applying this ratio, 104 (7.3%) samples, amongst the total of the 1400, were identified, distributed as follows: 2 samples of gas (0.15%) of possible microbiological origin; 38 (2.7%) of mixture and 64 (4.5%) that would have diagenetic origin, being the rest (92.6%) of the gas samples of really thermogenic origin.

At last, based on considerations presented by Harworth et al. (1985), it is possible to estimate that the type of fluid expected for this study area, would be predominantly liquid hydrocarbon with a minor amount of residual oil, condensed and gas.

CONCLUSIONS

- The interpretation of the evaluated area in this study allows identification of 13 areas with anomalous values of gasses.
- The detection of leaks of hydrocarbons, starting with the analyzed samples, allows the establishment of one oil system with thermogenic load in the evaluated area.

- Generally, the samples taken north of block have a biogenic origin and the ones taken south of the area have a thermogenic character.
- Finally, taking into account the considerations presented by Harworth et al. (1985), it is possible to estimate that the type of fluid as expected from the area under study would be predominantly liquid hydrocarbon, with some minor quantity of residual oil, condensate and gas.

REFERENCES CITED IN THE ORIGINAL WORK

Duchscherer, W. Jr. (1984). Geochemical hydrocarbon prospecting, with case histories: Tulsa, PennWell Publishing Co., 196 p.

Haworth, J. H., Sellens, M. and Whittaker, A. (1985). Interpretation of Hidrocarbons Shows Using Light (C1 – C5) Hidrocarbons from Mud – Log Data, AAPG Bulletin, V.69, No.8, pp. 1305-1310.

Krumbein W. C. and Graybill, F. A. (1965). An Introduction to Statistical Models in Geology.

Isaaks, E. H. and Srivastava, R. M. (1989). An Introction to Applied Geostatistics.

Schumacher, D. and Abrams M. A. (1996). Hydrocarbons Migration and its Near-Surface Expression, AAPG Memoir 66.

Whiticar, M. J. (1994). Correlation of Natural Gases with their Sources, Chapter 16, en Magoon L. B. and Dow. G. W., The Petroleum System – From Source to Trap, The Petroleum System: Memoir 60.

STRATIGRAPHIC SURVEY AND REALIZATION OF PETROGRAPHIC, PETROPHYSICAL, BIOSTRATIGRAPHIC AND GEOCHEMICAL ANALYSES IN THE PASTO-EL BORDO, CALI-BUGA, AND BUGA-CARTAGO AREAS (CAUCA-PATÍA BASIN)[1]

GEOESTUDIOS LTDA.

www.geoestudioscolombia.com

2008

SUMMARY

Facies analysis and interpretation of depositional settings were determined for the Tertiary sedimentary sequence on the Cauca-Patia Basin, SW Colombia. From north to south, three sectors were studied: North Cauca, South Cauca, and Patía. Analysis and interpretations herein presented were based on field data in conjunction with palynological, biostratigraphic, petrographic and geochemical (TOC) analyses. Our interpretative model indicates that a high proportion of sedimentary sequence was deposited on continental settings with a minor marine influence. Conglomerate-dominated levels were deposited on proximal and distal alluvial fans, proximal braided rivers and localized fan deltas. Fining-upward packages (Complete Sequences) indicate conditions of distal braided rivers, meandering rivers and flooding plains.

[1] Levantamiento de columnas estratigráficas y realización de análisis petrográficos, petrofísicos, bioestratigráficos y geoquímicos en las áreas de Pasto-El Bordo, Cali-Buga y Buga-Cartago (Cuenca Cauca-Patía). GEOESTUDIOS LTDA. Agosto, 2008.

Sand-dominated packages (Incomplete Sequences) with the common presence of intraclasts of underlying beds and intercalations of fine-grained sediments and thin coal beams, suggest a deposition on conditions common among sandy braided rivers with local development of flooding plains, marshes and swamps.

In three evaluated sectors there are clear evidences of transitional environments with marine influence. In the North Cauca Sector successions, deposited proximal to the shoreline and during the Early Miocene, are located on the top of the Cinta de Piedra Formation. In the South Cauca Sector units that suggest similar depositional settings are located toward the bottom of Upper Member of the Chimborazo Formation; however, deposition took place during the Middle Eocene. A similar situation is evidenced on the Los Chorros and is mostly marked on the overlying glauconite-bearing sandstones of the La Leona Member of the Guachinte Formation. In the Southern Patía Sector, the lower, calcareous portion of the Peña Morada Formation and herein denominated *Miembro Calcáreo* was deposited under conditions of a shallow platform, which in its turn is overlain by coarse grained sediments of alluvial fans (Conglomeratic Member), indicative of a dropping on the sea level. The latter unit is unconformably overlain by the Mosquera Formation, on which lower levels were deposited on a near shoreline setting. During the Miocene, the depositional system saw the most marked sea transgression with the deposition of Silty Fossiliferous Member of the Esmita Formation with better exposures on the Guanabanal Creek Section. Lithofacies associations in this unit reflect deposition on settings varying from coastal plains and tidal channels through shallow platform. The upper part of the Esmita Formation, known as the Sandy Member and the temporally equivalent, herein named the Reddish Silty Member, represents a regressive event with deposition under conditions common to continental settings. Palaeoambiental interpretations presented herein were supported on the analysis of ichnofossils and ichnofacies.

The determination of relative age of units and depositional environments was based on the analysis of pollen and microfossils (e.g., foraminifers). Analysis of pollen provided valuable information related to both the age of sediments and depositional settings, whereas the usefulness of the analysis of microfossils on calcareous sediments for age determinations was rather restricted.

Samples taken from the lower parts of the Cinta de Piedra Formation, in the North Cauca Sector, have TOC values up to 8.6 wt %, of type II and III kerogens, generally immature or close to the generation window. In the South Cauca Sector carbonaceous mudstones of the Guachinte Formation from Los Chorros, La Leona and La Rampla members exhibit good to excellent values for type II and III kerogens, generally immature or close to the generation window. In the Patía Sector, carbonaceous sediments on La Esmita Formation collected in Guanabanal Creek have TOC values up to 26.2 wt %, with type II and III kerogens, immature to overmature. In the latter location, sediments assigned to Mosquera Formation reported good TOC, reaching values up to 22.2 wt %, with type II and III kerogens, immature to overmature, possibly related to nearby intrusions or tectonism.

In order to determine the reservoir potential of different units, this study also involved the evaluation of petrophysical parameters such as porosity and permeability. Sedimentary rocks in the North Cauca Sector exhibit low degrees of porosity and permeability. However, these parameters increase in sandstones deposited on distal braided rivers and secondary channels, located preferably toward the lower and upper parts of the Cinta de Piedra Formation. In the Cauca Sur Sector, sandstones, conglomeratic sandstones and conglomeratic levels deposited on settings proper of braided meandering rivers and assigned to the Guachinte (e.g., La Cima Member), Ferreira Formation (Suárez Member) exhibit acceptable values for porosity and permeability. In the Patía Sector, similar values for petrophysical parameters herein evaluated have been obtained from sandstones of the Mosquera Formation.

In the North Cauca Sector, units with potential for seal rocks are located on the middle parts of the Cinta de Piedra Formation, conformed by thick beds of claystones to siltstones. In the South Cauca Sector, the fine-grained members of Los Chorros, La Leona and La Rampla constitute poor generating potential and immature units, which could behave as seal rocks. Likewise, in the Patía Sector, the argillic sediments of the Reddish Silty Member can operate as seal rocks.

Geochemical analyses indicate that fine grained sediments in the Cinta de Piedra Formation of North Cauca Sector exhibit a low potential as generating rock, despite the fact of the local presence of tracts with very good to excellent TOC values, up to 8.57 wt %.

Rocks that show the best values for porosity and permeability, similar to those with potential for being good reservoirs, correspond to those units deposited on fluvial settings (e.g., braided rivers).

The South Cauca Sector, more specifically on the Los Chorros, La Leona and La Rampla members of the Guachinte Formation with the dominance of carbonaceous mudstones, exhibits TOC values ranging from good to excellent, and constitute a potential source rock. Additionally, the La Rampla Member presents early maturity and a generation peak.

Reservoir rocks are located in the sandy levels of the Chimborazo Formation (Loma Larga Member), Guachinte Formation (La Cima, Los Chorros, La Leona and La Rampla members) and Ferreira Formation (Suarez Member).

The sandy levels of the Loma Larga Member of the Chimborazo Formation, deposited in braided and meandering rivers, exhibit good porosity and permeability values. The best generating unit is located in La Cima Member. The Guachinte Formation and sandy levels of Suárez Member (Ferreira Formation) present excellent values for porosity and permeability. These units were deposited in settings of braided and meandering rivers.

In the Patía Sector, levels of carbonaceous mudstones in the Esmita Formation (Limolitic Fossiliferous Member) exhibit TOC values typical for generating rocks. Sand-dominated levels of both the Esmita and Mosquera formations deposited on fluvial settings, exhibit a high potential for reservoir.

OBJECTIVE

According to the terms of reference, the main object of this project is to realize an integrated geologic work in the Cauca-Patía Basin, which would include the stratigraphic survey, the gathering of samples, and the realization of biostratigraphic, geochemical, petrographic and petrophysical analyses with the purpose of characterizing potential hydrocarbon source, reservoirs, and seals rocks of the basin.

LOCATION

The area is located in the Cauca-Patía Basin, between the Western and Central Cordilleras Foothills, in an elongated strip located approximately between the Pasto City (Nariño Department) in the south, and Cartago City (Valle Department) in the north, inside the jurisdiction of the Nariño, Cauca, Valle del Cauca, Quindío and Risaralda departments. There are 3 sectors (Figure 1), defined by the ANH, having a total area of 7569.052 km^2.

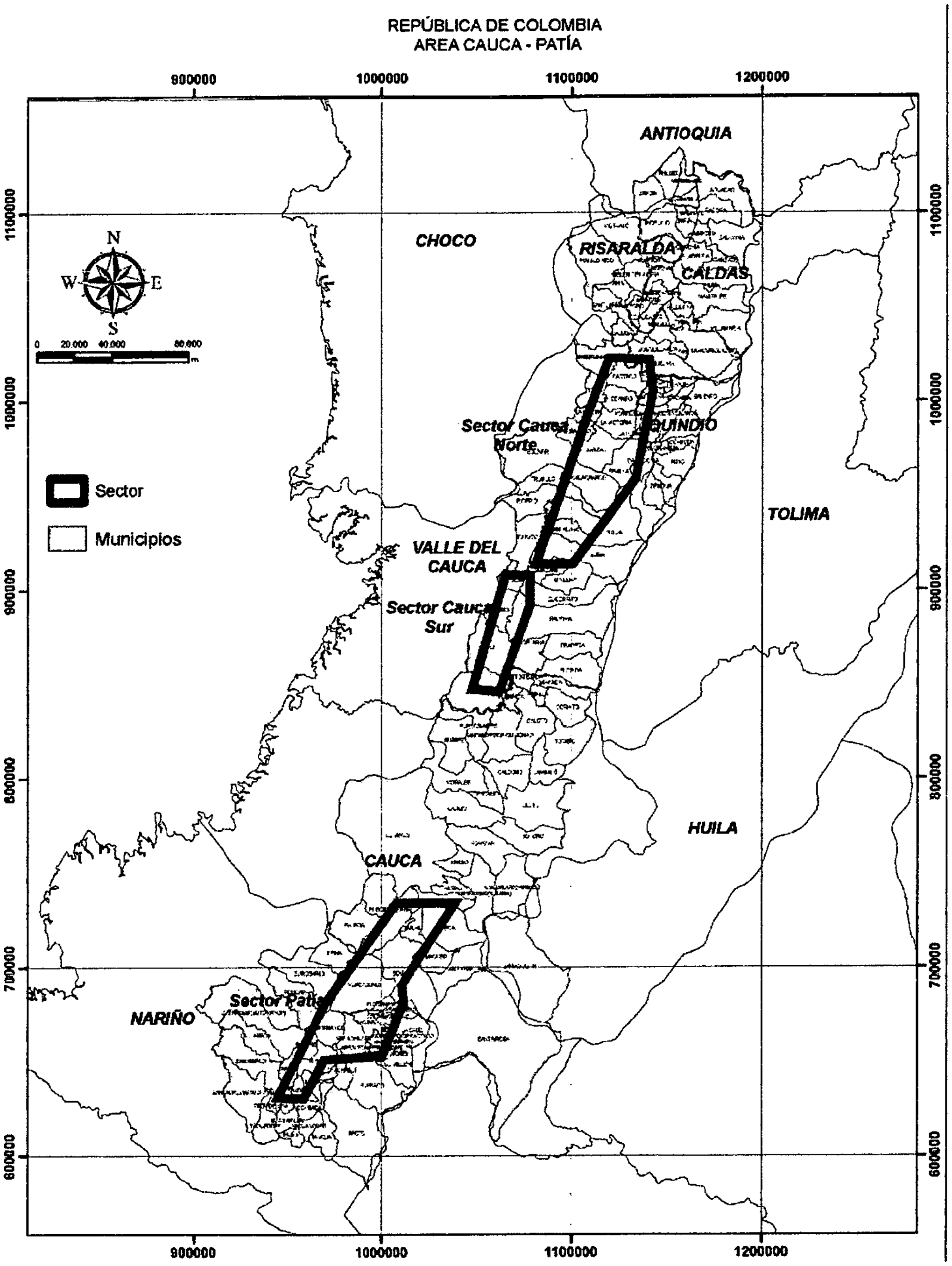


Figure 1. Map of location of study area.

METHODOLOGY

The general plan is presented as follows. It synthesizes the development of the project according to the sequence to be developed:

- Stage I. Technical information of the Area - OFFICE 1: This stage corresponded to the bibliographic compilation of the structural-geological information of the study region, evaluating the contributions of each publication, selecting the most relevant information for the realization of the project.
- Stage II. Field Work - FIELD I : North Cauca and South Cauca. The result of this first field stage was the description of 3613 m of stratigraphic columns with their respective polygonals, measuring of Gamma Ray and gathering of 1451 samples.
- Stage III. Processing of the information captured in field - OFFICE II : Digitization, processing and first interpretation of the information acquired in the field, as well as the selection of the samples gathered for the realization of biostratigraphic, petrographic, petrophysical and geochemical analyses (selection coordinated with the auditing of the project).
- Stage IV. Field Work - FIELD II : Patía Sector. 819 m of stratigraphic column were surveyed with their respective polygonals, measuring of Gamma Ray, 211 samples were gathered.
- Stage V. Selection of samples for Laboratory analysis - Laboratories - OFFICE III: second selection of rock samples for the realization of laboratory analyses; as well as the interpretation at a more detailed level of all information acquired in the field stages and laboratory analyses.
- Stage VI. a) Field Work / b) Selection of samples for laboratory analysis Laboratories - FIELD III and OFFICE IV: Patía Sector. 2101 m of stratigraphic column were surveyed with their respective polygonals, measuring of Gamma Ray, 828 rock samples were gathered.
- Stage VII. a) Processing of the information compiled, obtained in the Field, and results of laboratory analysis / b) Final Report elaboration / c) Revision, correction and verification of corrections of the Final Report - OFFICE IV.

In general, during the field phases, the measuring of stratigraphic columns was always carried out using the Jacob's Rod, lithologic descriptions, measurements of open polygonals with measuring tape, and compass at each section (Table 1). In addition to this, rock samples were extracted approximately every two meters, identified with a consecutive code and cathegorized according to their specific purpose (for geochemical, biostratigraphic, petrophysical and petrographic, analyses), detemined by their lithologic characteristics. In order to get Gamma Ray Total (U+Th+K) analysis of the outcrops the portable spectrometer GR-135B The Identifier Exploranium (SAIC) was used.

Table 1. Data of stratigraphic survey, sampling and laboratory analysis.

Sector		**North Cauca**	**South Cauca**					**Patía**				**TOTAL**
Section		**Cartago-Alcalá**	**La Cima**		**Guachinte River**	**North Guachinte River**	**Guachinte Techo River**	**Esmita River and Mosquera Fm. Sector**	**Guanabanal Brook**	**El Boquerón**	**La Despensa Brook**	**9**
		CA	LC	LCQ	RG	RGN	RGT	REandRE(M)	QG	EB	QD	
Formation		Cinta de Piedra	Chimborazoan dGuachinte		Guachinte	Guachinte	Guachinte and Frontera	Gr. Diabásico, Peña Morada, Mosquera	Gr. Diabásico, Mosquera, Esmita	Gr. Diabásico, Peña Morada, Mosquera	Gr. Diabásico, Peña Morada, Mosquera	
Total columns (m)		1803.0	738.0	0.0	456.0	306.0	310.0	212.0	1078.5	715.0	914.5	6533.0
Outcrops (m)		1009.5	527.0	0.0	369.0	184.0	239.0	210.5	776.3	640.0	603.8	4559.2
Covered (m)		793.5	211.0	0.0	87.0	122.0	71.0	1.5	302.2	74.9	310.7	1973.8
Gamma Ray (# records)		3448	1833	0	1241	614	801	703	25.92	2146	2009	15387
Polygonal delta		102	54	65	43	50	17	28	80	112	67	618
Pertrographic-petrophysical samples		319	184	40	78	56	86	25	168	91	180	1227
Biostratigraphic samples		210	130	2	105	49	50	5	144	173	85	953
Geochemical samples		2	2	0	32	3	5	0	1	0	0	45
Biostratigraphic-geochemical samples		45	3	0	39	0	11	44	29	26	68	265
Total		**576**	**319**	**42**	**254**	**108**	**152**	**74**	**342**	**290**	**333**	**2490**
Petrographic analysis		19	5	13	20	6	10	4	17	12	14	120
Petrophysical analysis		16	5	13	20	5	10	4	19	20	9	121
Biostratigraphic analysis	Palynomorph	66	39	1	26	14	18	10	50	26	87	337
	Micro paleontology	3	2	1	10	1	3	2	19	0	0	41
Geochemical analysis	TOC	11	11	0	13	3	7	10	33	15	50	153
	Pyrolysis	5	7	0	12	3	7	8	27	42	12	123
	Vitrinite	2	4	0	4	2	3	0	8	19	5	47
Total		**122**	**73**	**28**	**105**	**34**	**58**	**38**	**173**	**134**	**177**	**942**

RESULTS

Lithostratigraphic Units of the Cauca-Patía Basin

The units described are: Diabásico Group, Chimborazo Formation, Peña-Morada Formation, Guachinte Formation, Mosquera Formation, Cinta de Piedra Formation, Ferreira Formation, Esmita Formation.

Lithostratigraphy

For the stratigraphic analysis of each column, the most important facies characteristics, such as granulometry, geometry, contact of the layers, the physical, biogenetic present structures, the fossil content and other additional characteristics, such as color, fractures, visual porosity and Gamma Ray record (taken every thirty centimeters), were taken into account. The results of the different laboratory analysis and photographs were also considered.

In total, 28 main lithofacies were described and grouped according to their texture and composition. Seven types were identified: 1. Conglomerates; 2. Conglomerate fine sands; 3. Fine sands; 4. Heterolithic facies; 5. Fine sedimentation facies; 6. Calcareous facies; 7. Other facies. Once the facies in all columns were defined, they were grouped into faci associations, which allowed an interpretation of their environments and systems.

During the development of the work, ten (10) stratigraphic columns were described in nine (9) sections:

- One stratigraphic column in North Cauca Sector
- Four stratigraphic columns in South Cauca Sector
- Five stratigraphic columns in Patía Sector

In Table 2, a summary chart can be found. It identifies formations and outcropping members, the number of segments into which they were divided, the total thickness of the section, the thickness of the net outcrop and the locality where the sample was taken.

Table 2. Summary chart of the 10 stratigraphic columns, with formations, number of segments, total thickness, thickness of outcropping, and location.

STRATIGRAFIC COLUMN	FORMATIONS	SEGM.	THICKNESS (m)		LOCATION
			TOTAL	OUTCROPPING	
Cartago-Alcalá (CA)	Cinta de Piedra	16	1803	1009.50	Cartago-Alcalá Road
La Cima (LC)	Chimborazo, Guachinte	8	738	527	Cuchilla Las Piedras
Río Guachinte (RG)	Guachinte,	5	456	369	Guachinte River
Río Guachinte Norte (RGN)	Guachinte	3	306	184	
Río Guachinte Techo (RGT)	Guachinte, Ferreira	6	310	239	
Río Esmita (RE)	Grupo Diabásico, Peña Morada	7	169.5	168	Esmita River
Río Esmita (sector Mosquera)	Peña Morada, Mosquera	2	42.5	42.5	
Quebrada Guanabanal (QG)	Grupo Diabásico, Mosquera, Esmita	22	1078.5	776.3	Guanabanal Brook
Quebrada La Despensa (QLD)	Grupo Diabásico, Mosquera, Esmita	11	914.5	603.8	La Despensa Brook
El Boquerón (EB)	Grupo Diabásico, Mosquera, Esmita	9	715	640.1	El Bordo-Bolívar Road

In the Figure 2, the stratigraphic column obtained for the Cartago-Alcalá sections is shown as an example.

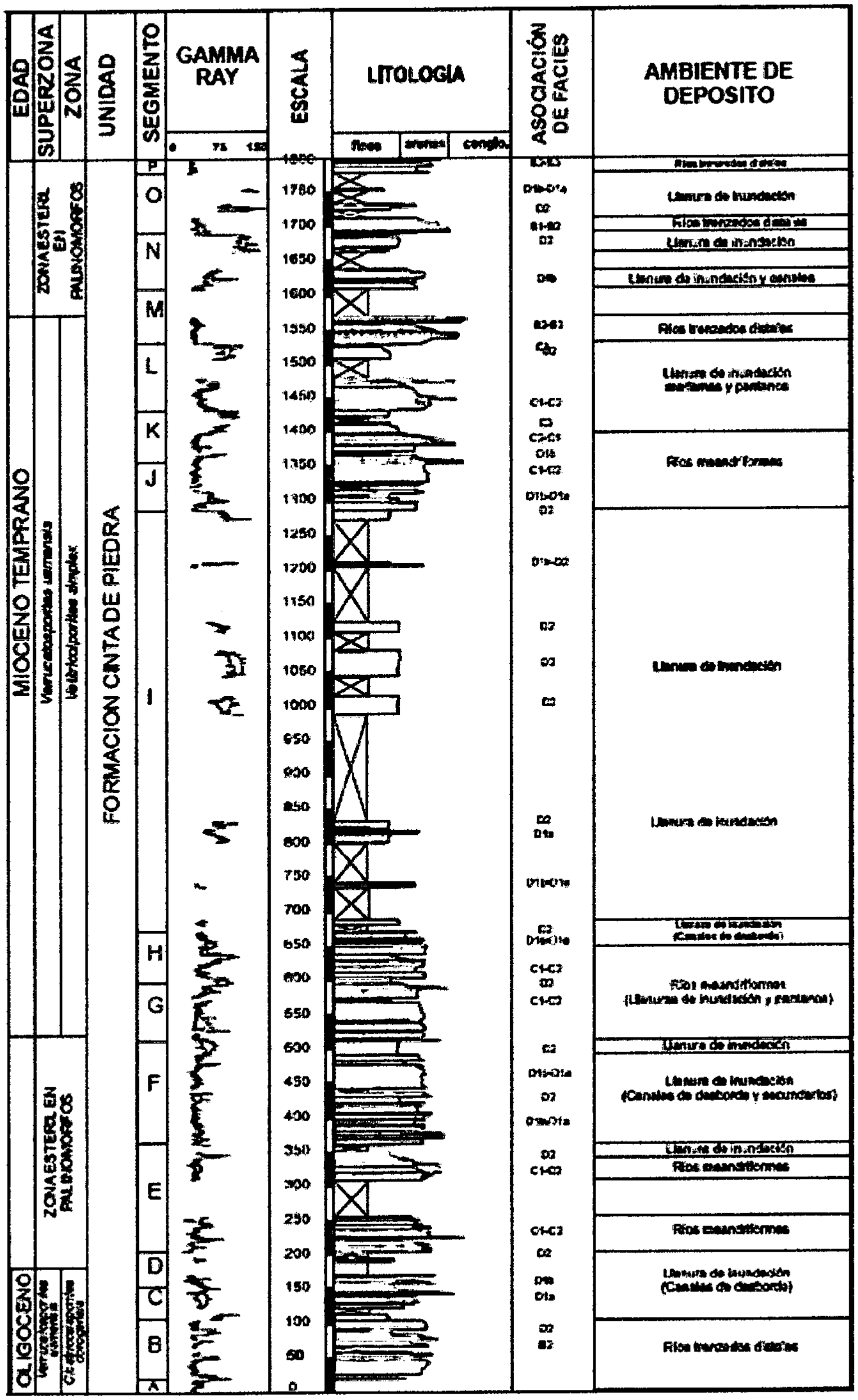


Figure 2. Cartago-Alcalá Section (CA); synthetic stratigraphic column of Cinta de Piedra Formation.

Gamma Ray Curves

A general description of the Gamma Rays radiation values is given, as well as their relation to lithology, deposit environment and the geometrical form, which the radiation values develop; this relation is made for each one of the stratigraphic columns, and they are also represented in each one of the synthetic columns. Figure 3 shows, as an example, the register for the North Cauca Sector, Cartago-Alcalá Section, Cinta de Piedra Formation.

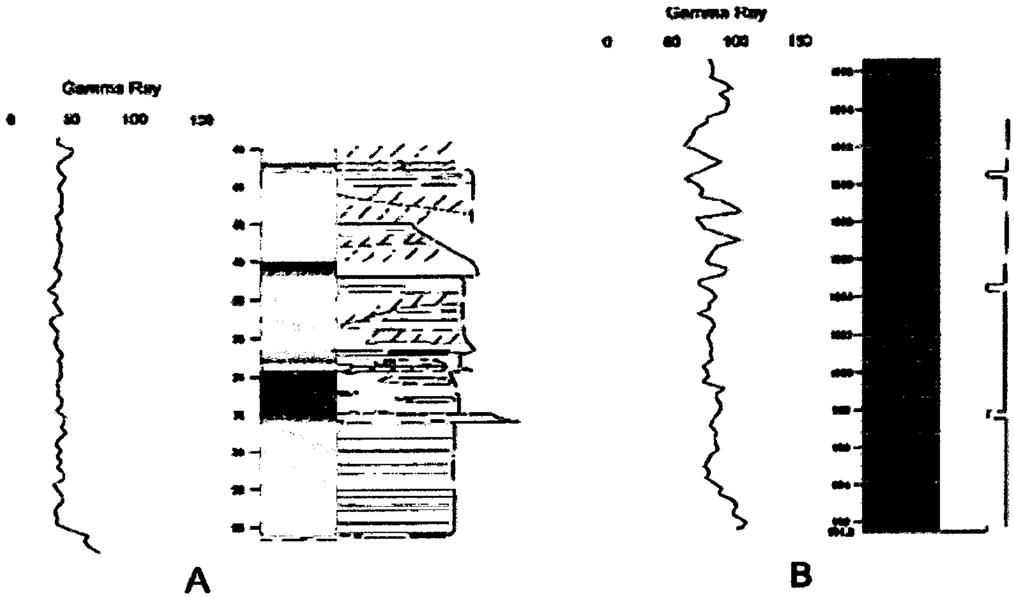


Figure 3. Regular serrated line having low gamma radiation values in fine sand (A); and irregular serrated line having intermediateGamma Ray values in sandy clay and sandy mud (B).

Formations and Deposit Enviroments

The units present in the various studied sections are presented, where the main sequences, and facies associations, their environments, ages, thickness, and other characteristics are described. Table 3 synthesizes some of the most important characteristics including: sectors and studied sections, names of the formations, members, segmentation, location in the columns, measured thickness and ages.

Table 3. Summary chart where all the studied units, sections, sectors, identified members, measured thickness, and ages assigned from palynomorphism are presented. The measured thickness (in boldface correspond to the complete thickens of the member).

SECTOR	SECTION	FORMATION	MEMBER	SEGMENTS	LOCATION IN COLUMN (m)	THICKNESS (m)	AGE
North Cauca (Cartago)	Cartago-Alcalá	Cinta de Piedra		B-P	19.4-1803	1785	Early Oligocen Miocen
	La Cima	Chimborazo	Loma Larga	A-F	36.5-640.5	604	Middle Eoceno
	La Cima		La Cima	G	640.5-728	**87.5**	
	Río Guachinte		Los Chorros	B	2-277	**275**	Middle Eoceno
South Cauca (Jamundí)	Río Guachinte		La Leona	C	277-320	**43.5**	
	Río Guachinte			D-E	320-455.5	135.5	
	Río Guachinte norte	Guachinte	La Rampla	A-C	0-306	306	Middle Eoceno
	Río Guachinte techo			A	0-66.5	66.5	
	Río Guachinte techo	Ferreira	Suárez	B-F	66.5-309.5	**243.5**	Middle Eoceno
	Río Esmita	Peña Morada	Calcáreo	B-F	6-83	77	Paleogen
			Conglomerático	G	83-169	86	
	Río Esmita			B	4-42	38	
	Q. Guanabanal	Mosquera		B-G	2-243	**241**	Late Oligocen to Middle Miocen
	Q. La Despensa			B-E	10-219	**209**	
	El Boquerón			B-C	10-176	**166**	
	Q. Guanabanal			H-N	243-649.5	**406.5**	
Patía (El Bordo)	Q. La Despensa		Limolítico fosilífero	F-H	219-619.9	**400.9**	
	El Boquerón			D-F	176-430	**254**	
	Q. Guanabanal			O-T	649.5-954.5	**305**	
	Q. La Despensa	Esmita	Arenáceo	I-J	619.9-819	**199.1**	Late Oligocen to middle Miocen
	El Boquerón			G-H	430-660	**230**	
	Q. Guanabanal			U-V	954.5-1078.5	124	
	Q. La Despensa		Limolítico rojizo	K	819-915	96	
	El Boquerón			I	660-715	55	

Laboratory Analysis

It includes the activities of laboratories and their respective reports on results for biostratigraphic, petrographic, petrophysical and geochemical analyses, which integrate themselves with the lithostratigraphy in order to obtain the characteristics of the various sections and studied units.

Biostratigraphic Analysis

The objective of this activity was to establish the age, as well as to obtain supplementary arguments with respect to the possible deposit environment of the studied units. The palynologic analysis and those of microfossils (foraminifers) was carried out in 337 rock samples coming from nine stratigraphic sections belonging to the Cauca Patía Basin Stratigraphic Columns Project.

Petrographic Analysis

With realization of petrographic analyses, the characteristics that allow to classifiy rocks and to establish its quality as a potential storage of hydrocarbons were obtained. This analysis was performed in 120 rock samples corresponding to fine sand, collected in the 10 stratigraphic columns and 9 stratigraphic sections.

With the elaboration of petrographic analysis in the thin sections – conducted with polarized light microscope – the size of the grain, the shape, contacts, selection and textural maturity were identified in the texture. The type of matrix was identified, the composition was determined (by differentiating between terrigenous, alochemicals, and orthochemicals). Appreciation of the diagenesis, and calculation of porosity were carried out. The modal percentage was determined by counting 300 points according to rock granulometry, identifying them in adequate optic fields and ensuring they were representative of the sample. Based on these percentages, the sample was classified using the Quartz-Feldspars-Lithic composition triangle (QFL). In calcareous rocks the description, determination, and quantification of the Orthochemical-Alochemical components were made. In the calcarenite rocks the detrital (terrigenous) components were differentiated. For the elaboration of the thin sections, the orientation of the rock sample cut, with respect to its top and base, was kept in mind. Also, vacuum impregnation (blue epoxy) for determining primary porosity, secondary one, and microporosity, and tinting for carbonates were included.

In the igneous rocks, cristallinity, general and particular texture, and structure were described. The minerals description is arranged according to their importance: essential, characterizing, primary accessories, secondary accessories and alteration minerals.

Petrophysical Analysis

This consisted in carrying out - at laboratory level - basic petrophysical analysis, such as porosity, permeability and grain density, in order to obtain priorities and potentiality of the reservoir rock in the studied units (Table 4). This petrophysical analysis was carried out in 121 rock samples corresponding to fine sands gathered in the 10 stratigraphic columns.

Table 4. Basic petrophysical analysis.

SECTOR	FORMATION	MEMBER	POROSITY, %	PERMEABILITY, mD	COMMENTS
North Cauca	Cinta de Piedra		8.3	0.7	Results acceptable as reservoir
South Cauca	Chimborazo	Loma Larga	8.3	4.21	Results acceptable as reservoir rock
	Guachinte	La Cima	9.7	1.051	reservoir rock qualified as acceptable
		Los Chorros	9.6	0.56	from low to poor quality as reservoir.
		La Leona	10.46	1.11	some possibilities of storing rock
		La Rmpla	10	0.923	zone of average interest as reservoir
	Ferreira	Suárez	8.9	0.968	zones from low to average economic interest.
Patía	Mosquera		10.3	0969	acceptable conditions as reservoir rock
	Esmita	Limolítico fosilífero	3.4	0.01	very poor values as reservoir rock
		Arenáceo	7.2	0.030	results obtained vary from average to poor, as reservoir rock
		Limolítico rojizo	8.2	0.309	rock is poor as reservoir

Geochemical Analysis

The objective of the geochemical analyses was to determine the amount, quality and maturity of organic texture, which rock has to have, in order to establish the type of hydrocarbons that can be found in the basin, as well as characterize possible rocks, which generate hydrocarbons in studied geological sections. A total of 323 analyses were carried out in 153 samples of different rocks, gathered in the 9 stratigraphic sections.

A generating rock is a rock capable of generating and expelling oil in order to form accumulations of oil and gas, for this reason the three main criteria of a generating rock will be analyzed. That are: organic richness (quality and amount), type of kerogen and thermal maturity. A total of 153 samples were analyzed by total organic carbon test (TOC). In the samples with best results of TOC (>0.5%) analysis of pyrolisis rock evaluation, analysis of vitrinate reflectance, and analysis of organic matter were carried out.

In Tables 5, 6, 7, and 8 are presented geochemical parameters, as well as the qualifying thermal ones used for describing the potential generation of oil, rock maturity, relative amount of hydrocarbon generated, and type of kerogen.

Table 5. Grading used for the oil potential.

Oil potential	TOC (% weight)	S1 (mg HC/g rock)	S2 (mg HC/g rock)
Poor	0-0.5	0-0.5	0-2.5
Favorable	0.5-1.0	0.5-1.0	2.5-5.0
Good	1.0-2.0	1.0-2.1	5.0-10
Very good	2.0-4.0	2.1-4.0	10-20
Excellent	>4.0	>4.0	>20

Table 6. Grading used for the maturity of rock based on temperature.

Pyrolysis temperature	Tmax °C
Immature	<435
Early maturity	435-445
Rocks at peak of generation	445-450
Rocks at the end of oil window	450-470
Overmature	>470

Table 7. Grading of potential of contribution of immature kerogens (amount and products) based on hydrogen index.

Index of hydrogen (IH)	Main products	Relative amount
<50	Gas	Small
50-300	Oil-Gas	Small
300-450	Oil	Moderate
450-600	Oil	Big
>600	Oil	Very big

Table 8. Type of kerogen, ambit and generation of hydrocarbons.

Type	Ambit	Generation of hydrocarbons
I	Lacustrian	Oil
II	Marine	Oil
III	Continental	Gas/Oil
IV	Worked and oxidized	

In Table 9 a summary of parameters per basin area is presented:

Table 9. Summary of parameters.

Sector	Formation	Member	TOC %	Tmáx	IH	IO	Ro	COMMENTS
North Cauca	Cinta de Piedra		0.43	432	65.95	77.75	0.48	potential from average to good for the obtainment of gas, and, in less importance, oil. The rock is, generally, immature having some samples in windows of generation
South Cauca	Chimborazo	Loma Larga	0.52	439	71.61	28.80	0.68	moderate potential for gas generating and low for oil generating
	Guachinte	Los Chorros	2.88	436	122.67	34.31	0.57	interesting potential for the gas generating, but low for the petroleum generating
		La Leona	3.01	441	139	13		good potential for the gas generating and favorable for petroleum generating
		La Rampla	4.98	443	174.22	17.50	0.63	TOC values, from very good to excellent for gas generating and favorable for petroleum generating
	Ferreira	Suárez	1.79	447.5	135.93	24.53	0.76	TOC values, from very good to excellent for gas generating and low for petroleum generating
Patía	Peña Morada	Calcáreo	1.17	487.5	19.00	23.61		Good TOC values, but probably generated with the influence of an action, as a result of high thermal maturity
	Mosquera		2.73	433	102.94	49.02	0.45	very good TOC values, with an organic matter type II and III, which are immature
	Esmita	Limolítico fosilífero	1.83	429	109.64	35.46	0.51	good TOC values with organic matter types II and III, having favorable potential for gas generating and low for petroleum generating
		Arenáceo	3.12	427	169.09	48.96	0.53	TOC values were reported and organic matter types II and III, indicators of rock in the thermic immaturity stage
		Limolítico rojizo	2.14	428	212.23	57.13	0.49	good TOC values were reported and organic matter types II and III, thermally immature

Petroleum Geology

Lithofacies and biostratigraphic definitions were carried out. The characterizing of outcropping rocks (generating and/or reservoir), and evaluating their importance as prospective zone for hydrocarbons. Table 10 shows the summary of rocks characteristics.

Table 10. Summary of rocks characteristics.

Sector	Source rock	Reservoir rock	Seal rock	Migration	Traps
North Cauca	Low potential	The fine sands and conglomerates of the Cinta de Piedra Formation are the best reservoir rocks of the region	Seal rock is represented mainly by a very thick succession of homogeneous muddy, homogeneous and sandy mud	There is no evidence	Stratigraphic type
South Cauca	Good potential	Reservoir rocks are located within sandy levels. The best reeservoir rock is found in La Cima Member	Seal rock corresponds to clay and mud from the Guachinte Formation (La Leona Member), at different levels of fine sedimentary from the Ferreira Formation and to the fine basal sequence of the Esmita Formation	There is no evidence	Structural type
Patía Sector	Poor potential, although with very good TOC potential	The main reservoir rock is the Mosquera Formation	The regional seal is made of shales at the base of the Esmita Formation and local seals would be formed by intraformation shales of the Mosquera Formation	There is migration	Structural type

REFERENCES CITED IN THE ORIGINAL WORK

Barrero, D.; Martínez, J.; Vargas, C.; and Pardo, A., (2007). Petroleum Geology of Colombian Basins in ANH, Colombian Sedimentary Basins. Bogotá.

Barrero, D.; Laverde, F. (1998). Estudio Integral de Evaluación de la Geología y Potencial de Hidrocarburos de la Cuenca "Intramontana" Cauca - Patía, ILEX - ECOPETROL, 4 vol. ISN 48828, Informe geológico 4977, Santa fe de Bogotá.

Cáceres, H. (1988). Reconocimiento Geológico de Campo Cuenca Valle del Cauca y del Patía. ECOPETROL–ESRI, 68 p. ISN 15174 Informe geológico 1613, Bogotá.

Chamberlain, A. (1984). Surface Gamma Ray Logs: Tool for frontier areas. AAPG Bulletin, Vol. 68 (8), pp. 1040-1043.

Dueñas, E. and Aguilera, H. (1978). Informe Geológico Preliminar del Valle del Cauca Sectores Norte y Central. ECOPETROL, Informe 608, 51 p.

ECOPETROL – ESRI (1988). Valle del Cauca Field Report. Volume I - Text. Report 88-0012.

ECOPETROL – ICP (1992). Modelo Estructural en la Subcuenca del Patía y su implicación en la Acumulación de Hidrocarburos. V Congreso Colombiano del Petróleo, Memorias; pp. 178 - 190. Santafe de Bogotá.

ECOPETROL – ICP (1991). Evaluación Cuenca Patía - Segundo Informe Trimestral. Informe EPIS Nº 3063. Santafe de Bogotá.

INSTITUTO COLOMBIANO DEL PETRÓLEO (1991). Proyecto Evaluación Cuenca Patía. Informe final, 118 p. 7 vols. y 63 anexos, ISN 25645, Informe geológico 3071.

Leeder, M. (1982). Sedimentology: Process and Products. Unwin-Hyman, London, 344.

Martínez, J.; Rubio, F. (1991). Arquitectura Facial de las Unidades Tectosedimentarias Terciarias, con la Evolución Geodinámica de la Subcuenca del Alto Patía, Cauca - Colombia. Trabajo de Grado, Departamento de Geociencias, Universidad Nacional de Colombia, Bogotá.

McCourt, J. (1984). The Geology of the Central Cordillera. The Departament of Valle del Cauca, Quindío and NW Tolima (Sheets 243, 261, 262, 280 and 300). INGEOMINAS–Misión Británica.

Moore, C. (1963). Handbook of Subsurface Geology. pp. 93-97.

Pérez, G.; Numpaque, L. (1980). Estudio Geológico de la Subcuenca del Río Patía. ECOPETROL, Informe geológico 706, p. 48, Bogotá.

Rodríguez, G.; Velandia, G. (1980). Evaluación de la Información Geológica y Geofísica de la Cuenca del Valle del Cauca, ECOPETROL, ISN 14252, p. 75, Informe Geológico 2534, Caja 920.

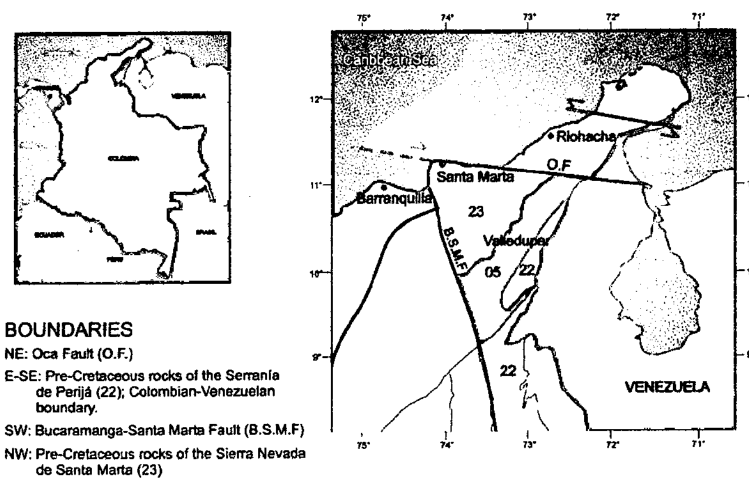
Schlumberger Ltd. (1972). Fundamentos de la Interpretación de perfiles.

Yepes, C.; Gelvez, I. et al. (2000). Resumen Geológico y Operacional del Pozo Juga-1 Prospecto Cauca-Patía. ECOPETROL Gerencia Occidente. Santafe de Bogotá.

2. CESAR – RANCHERÍA BASIN

This intermontane (broken-foreland) basin is bounded to the northwest by the Pre-Cretaceous rocks of the Sierra Nevada de Santa Marta. The northeast limit is the sharp trace of the Oca Fault; to the east-southeast it is limited by the pre-Cretaceous rocks of the Serranía de Perijá and the Colombian-Venezuelan boundary and to the southwest the trace of the Bucaramanga Fault (Figure 1). This basin has a general orientation N30°E and the Verdesia High divides it in the southern Cesar and the northern Ranchería Sub-Basins.

CESAR RANCHERÍA BASIN
LOCATION AND BOUNDARIES



SCHEMATIC CROSS SECTION
CESAR - RANCHERIA BASIN

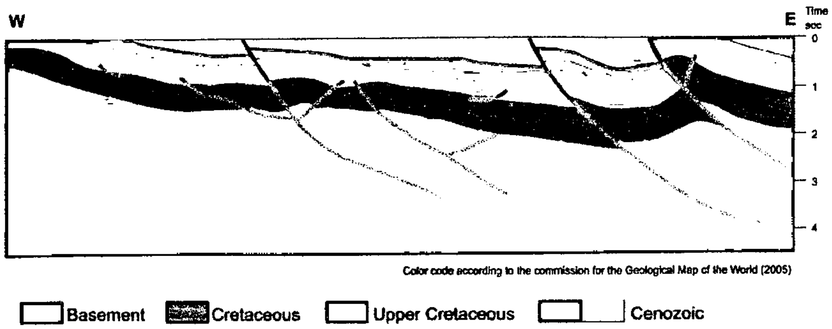


Figure 1. Cesar Ranchería Basin.

GEOLOGICAL CARTOGRAPHY CESAR – RANCHERÍA BASIN[1]

GEOESTUDIOS LTDA.

www.geoestudioscolombia.com

2006

SUMMARY

Geological cartography works and stratigraphic survey at the Western Foothill of the Serranía del Perijá, between Codazzi and La Jagua de Ibirico, were carried out as part of an exploration program of the Agencia Nacional de Hidrocarburos (ANH) in the border area of the Cesar-Ranchería Basin.

The stratigraphically oldest rocks in the area correspond to La Quinta Formation, which consists of tuffs accumulated in environments of continental stratum-volcanoes intercalated with clastic facies of arkose fine sands, conglomerates, and mudstones linked to fluvial and lacustrian environments. Above them lie incomplete sequences of grain-decreasing conglomerates, conglomerate sands and thick-grain sands with crossed stratification, accumulated in fluvial surroundings, which conform the lower part of the Río Negro Formation.

At the middle of the unit, there appear faci variations that include complete and incomplete grain-decreasing sequences, with mid-grain fine sands and planar crossed stratification, locally conglomeratic, followed by bioclastic fine sands, and bioclastic, laminated mudstones accumulated in fluvio-estuarine ambits. While the sedimentary rocks of the base present low porosity because of the intensive cementation, the ones at the middle have various crumbly levels impregnated with hydrocarbons.

---

[1] Cartografía geológica Cuenca Cesar-Ranchería. Informe Final. GEOESTUDIOS LTDA. Julio, 2006.

Important variations of thickness are present at the Río Negro Formation. Northern of Codazzi the unit disappears, while at the south, e.g., at the Maracas River, thickness is about a thousand meters. The Lagunita Formation continues in transitional concordant contact. This formation is characterized by thick and very thick strata of wackestone, mudstone, grainstone and fossiliferous packstone with calcareous mudstones accumulated in shallow internal platform environments. This unit presents relatively constant thickness from 340 m to 400 m. The Ánimas Member of the Aguas Blancas Formation lies over the last one, dominated by black shales (rich in organic matter). It shows local development of abundant concretions and minor interposition of lightly fossiliferous mudstone (deposited at a mid-platform). The thickness of this unit is approximately 270 m. The highest part of the Cretaceous section corresponds to the Tocuy - Maraca members, which consists in a very thick strata and thick strata of limestone with mid-level intercalations of calcareous mudstone. To the east of the La Jagua de Ibirico Municipality, the Los Cuervos Formation was described. It is characterized by massive mudstone facies, thin layers of carbon, fine sand with bioclastic, undulated lamination, and heterolytic facies that indicate marsh environment with marine influence. Towards the middle part of the unit two metric packages of fine sands with a tangential crossed stratification accumulated in strictly fluvial environment are observed.

Structurally, the area conforms a monoclynal with layers sloping to the NW 20° - 30°. At the lowest part of the foothill there are folds with layers sloping to the SSW about 10° and that are continued all along this foothill. At the valley of the Sicarare River there is a sinestral fault - named in the same way -, which truncates great part of the stratigraphic succession, and produces an horizontal displacement of 7 km. Its arrangement near the surface is interpreted as essentially vertical. The stress indicators, diaclasses and fluted faults indicate, at least two main stretching directions. The most common one appears in the diaclasses and it corresponds to an stretching axis in NE-SW direction, which is parallel to the main axes of folding, and it would be related to this deformation. The other tendency to stretching, has WSW-ESE direction and it corresponds to compressive stress, which leads to the formation of the Sicarare Fault. Assuming that evaluated mesoscopic faults correspond to a conjugated arrangement, the stress directions show great scattering. The mesoscopic faults correlate better with schemes that correspond to faults with complex arrangements.

LOCATION

The work includes two areas: north and south (Figure 1). The polygon corresponding to the northern area covers 457 km^2, where geological cartography and stratigraphic columns survey were carried out. At the southern part, work area covers 101 km^2, in which stratigraphic columns were adquired with their respective sampling.

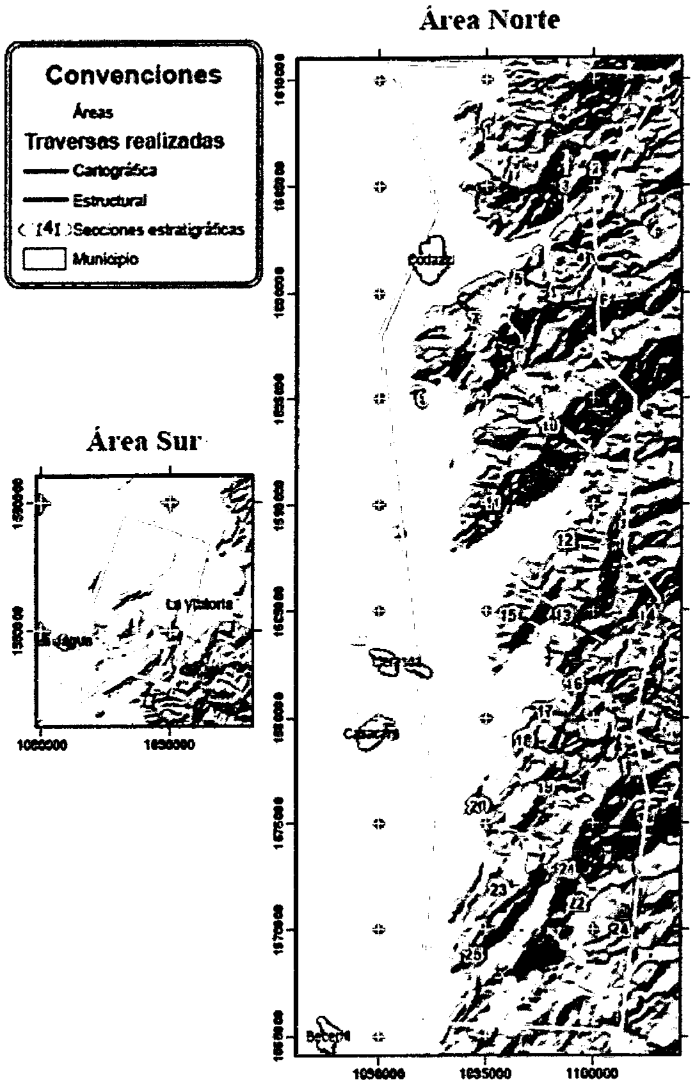


Figure 1. Map of the site with location of traverses and measured stratigraphic sections.

METHODOLOGY

The first stage of this project included compilation, analysis and, evaluation of the geoscientific and cartographic information. Later on, photo-geological maps based on the information consulted during the first stage were constructed. After that, the stage of verification of field was carried out. That included the geological cartography at the northern area, the acquisition of stratigraphic columns, and sampling of oil seeps in both areas.

As a result, a map at scale 1:25000 was obtained with stratigraphic, as well as structural information. In the cartographic traverses cartographic information (GPS, coordinates), structural information (azimuth, diaclasses) and stratigraphic information (name of the formation, thickness of the strata, internal and external structures, contacts, types of rocks, size of grain, caliber, roundness, visual porosity, color, matrix and cementing) in each field station were included.

With regard to structural traverses, the description and integration of the identified elements and structural systems was made. At each station, data of strike, dip, the diaclasses (type of fracture, separation, filling material, length, etc.), and of foliation were obtained. The stratigraphic survey and sampling were carried out in both areas, and it included 1000 m of stratigraphic columns at scale 1:200 with measuring ofGamma Ray every 30 cm.

The facies were named keeping in mind the Miall (1977) methodology but adapted and translated into Spanish. In general, the first and sometimes the second letter represent the lithology.

Regional Geology

Geologically, the work area is located at the western foothill of the Serranía de Perijá, which, on its turn, is located eastern of the Cesar-Ranchería Basin (Figure 2). Although in previous works a structural style dominated by thrust faults (Kellogg, 1981, Baquero et al., 1990) has been interpreted, this work suggest that, at least in the cartographic area the tectonic style is related to course faults.

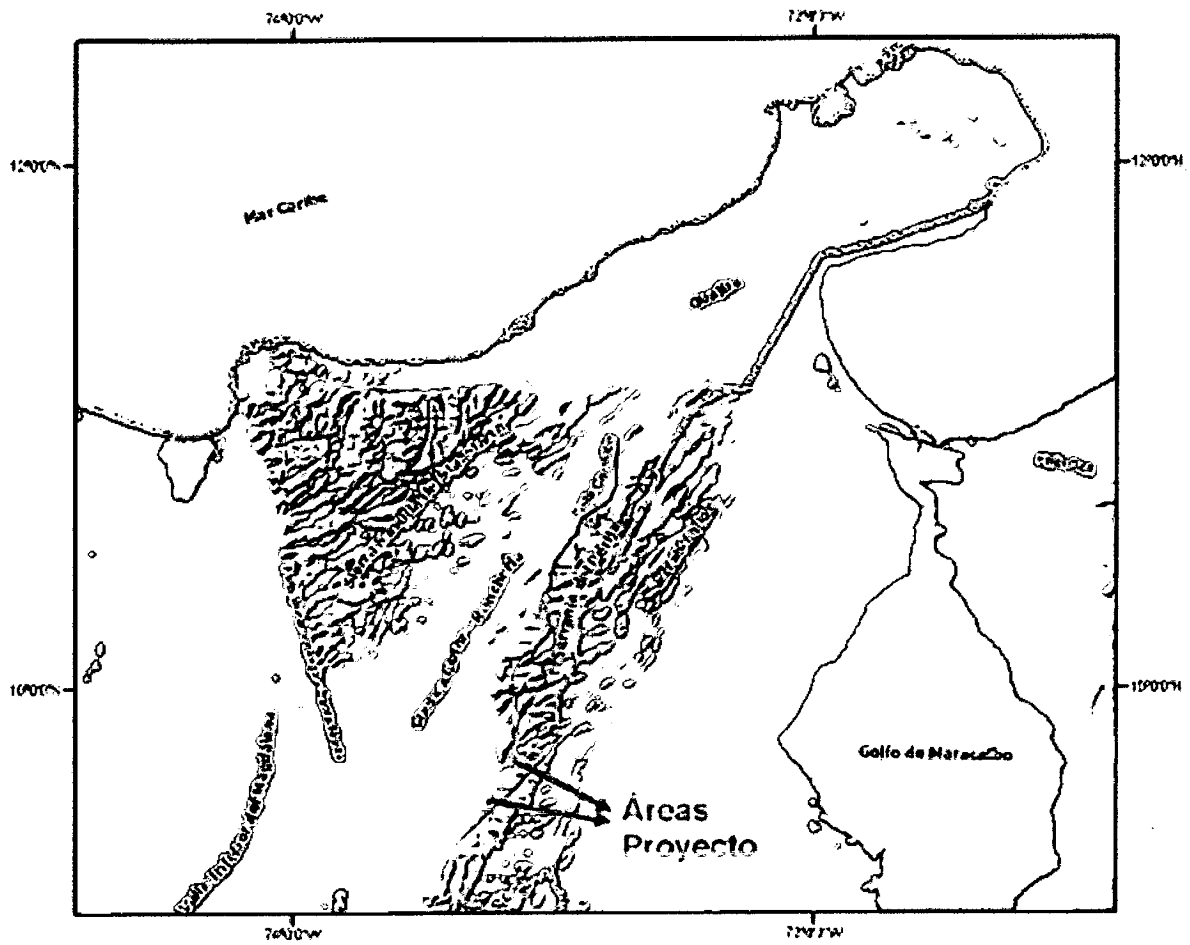


Figure 2. General geological view of location of the study area.

Figure 3 shows the identified units during the cartography works.

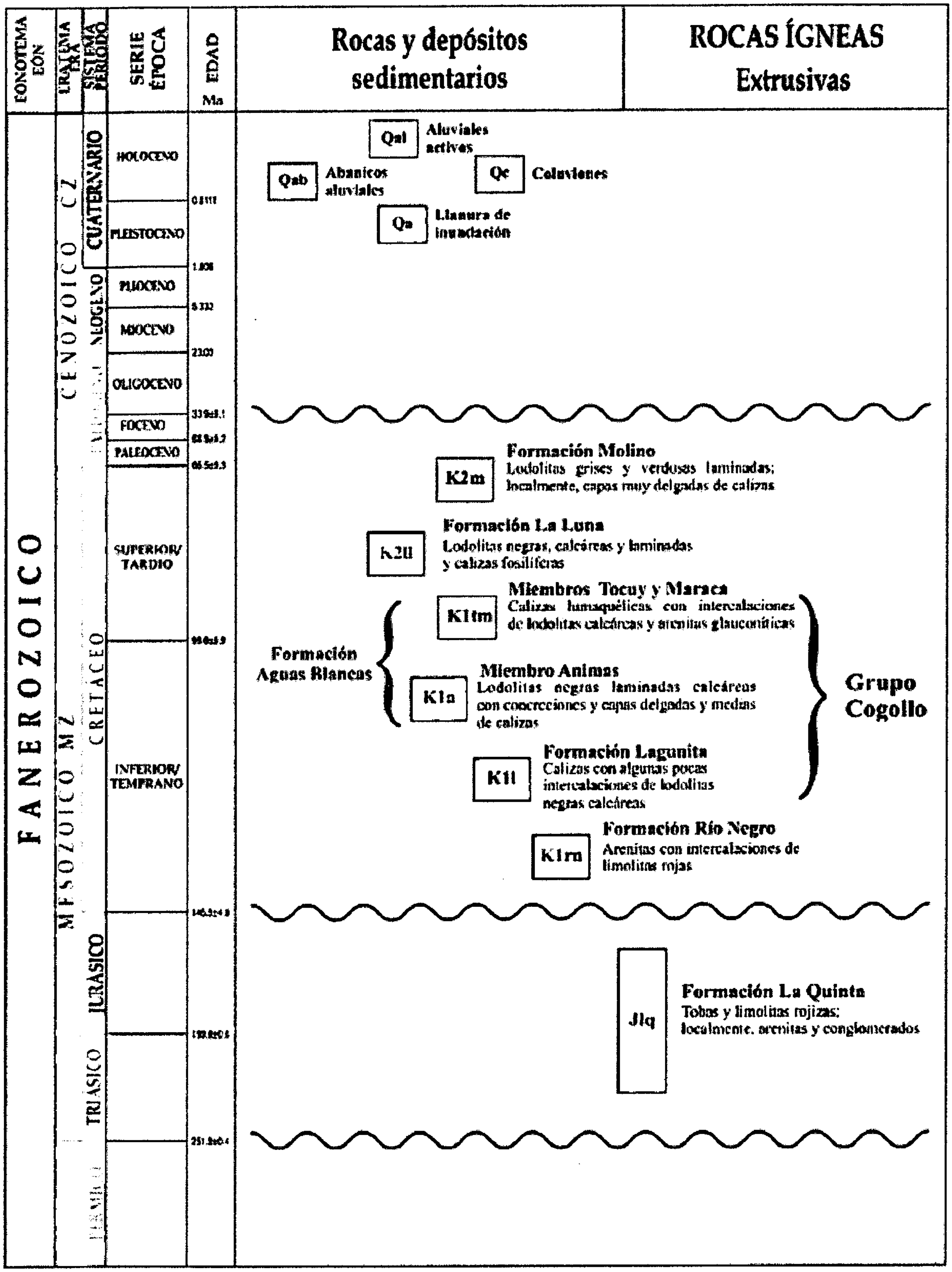


Figure 3. Identified units in the sudy area.

Geologycal Cartography

The information used in the geological map includes information of 536 field stations with 535 gathered rock samples, and more than 600 representative photographs. This work was carried out by the method of traverses, and it included 8 structural traverses, and 17 cartographic traverses with total lengths of 32 and 74.4 km, respectively.

Identified units

In the north of the study area, fully distributed rocks of La Quinta, Río Negro, Lagunitas, and Aguas Blancas formations were found, while La Luna and Molino formations were the only ones reported in the southwestern sector. The Barco Formation was not observed, and related to Los Cuervos Formation, only exposures were found in the southern area. Figure 4 represents the generalized stratigraphic column of the units that outcrop in the study area.

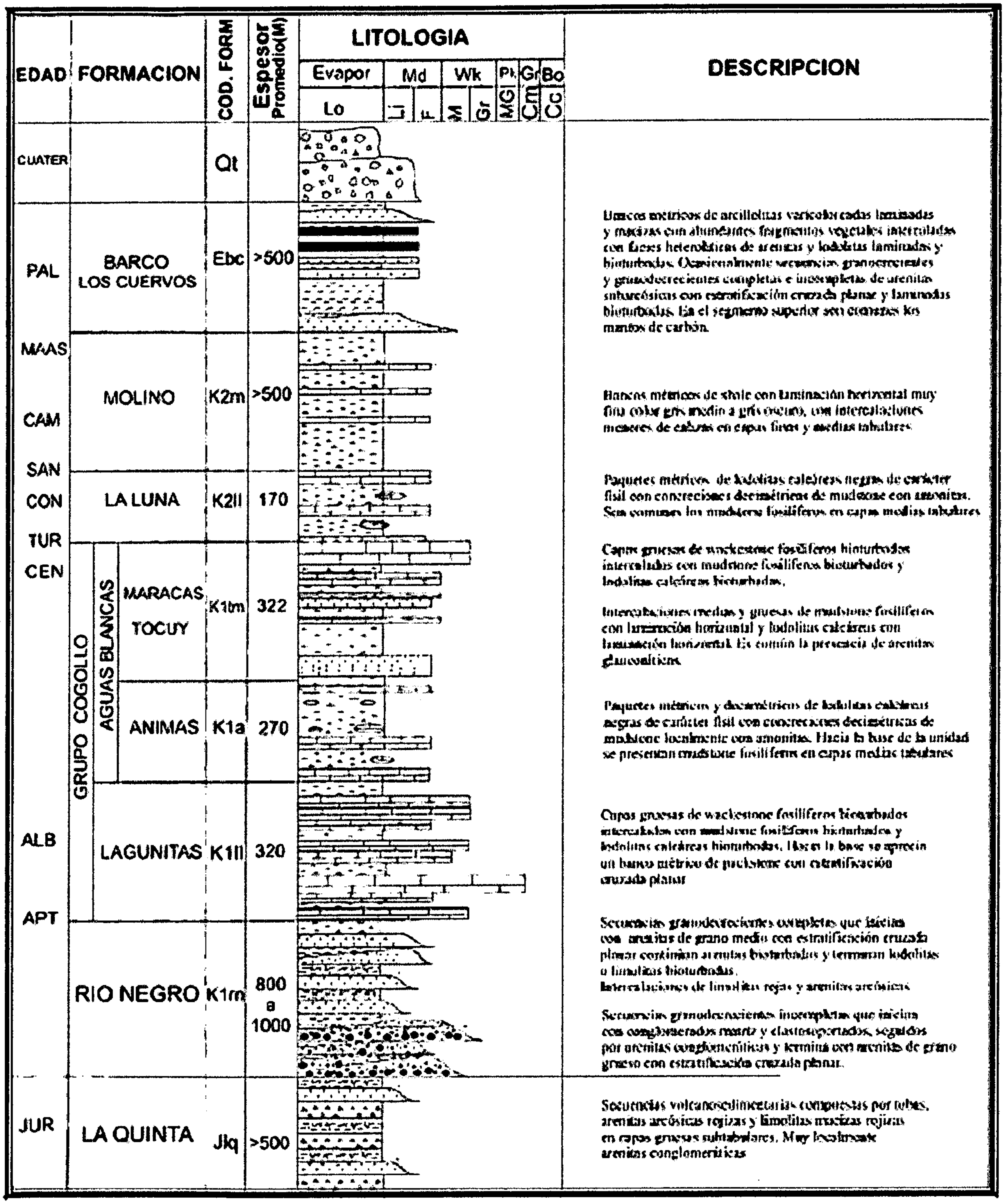


Figure 4. Generalized stratigraphic column of the Cesar-Ranchería Basin between the Codazzi and La Jagua de Ibirico Municipalities.

Stratigraphy

The total length of measured stratigraphic section was 1300 m, of which 950 m were described. In the northern area, the Cretaceous units were surveyed, and in the south, the Cuervos Formation was described.

Types of Facies

In total, 77 facies types were identified and characterized taking into account the following main features: textural, lithologic, physical sedimentary structures, and biogenic sedimentary structures, found along the surveyed stratigraphic columns and the outcrops described in the cartographic and structural traverses. These facies were summarized in 11 types: 1) conglomerates and conglomeratic fine sands; 2) laminated fine sands; 3) bioclastic laminated fine sands; 4) bioclastic fine sands; 5) fine facies; 6) calcareous fine facies; 7) heterolythic; 8) packstone and grainstone; 9) wackestone; 10) mudstone and 11) miscellaneous facies.

Structural Geology

Structurally, this sector of the Cesar-Ranchería Basin has been interpreted as the result of compressive stresses, which produce a structural style characterized by fault-bend folding (Baquero et al., 1990). Evidences related to this structural model were not found during this work. On the contrary, this work suggests that the structural style is related to the folding of the sedimentary covering with course superposed movements, which originated the only recognized regional fault. On the other hand, in order to describe and to analyze the position of its layers and structures, the area was divided into four structural domains, starting from the main sloping tendencies, which, on its turn, defines folding trains.

CONCLUSIONS

- In spite of the presense of fine sands of thick and very thick grain facies, the fine sands of the lower half of the Río Negro Formation are quite cemented and their porosity is quite low, while the ones of the middle of the unit, even of finer grain, have various crumbly levels, which present better characteristics in their porosity. In fact, these were the only fine sands at the Maracas River Canyon, where clear manifestations of hydrocarbons were found.

- Towards the north, the Río Negro Formation disappears, and it is the southern part, where it presents greater thikness, around 1000 m. On the contrary, the other units of rock show essentially constant thickness along the area. Southwest the area, units with important characteristics of generating rock are present, such as: banks of laminated black shale rich in organic matter from the La Luna Formations and from the Ánimas Member of the Aguas Blancas Formation.
- It is necessary to start new campaigns for aquiring detailed columns of units such as Río Negro Formation, in order to define the stratigraphic succession with greater precision, as well as the facies lateral and vertical variations. This unit has, in our judgment, an important potential as a reservoir rock.
- The limestones of the Lagunita Formation and of the Maraca Member from the Aguas Blancas Formation present important fracturing in some sectors, which gives them great potential as fractured reservoir.
- Regard to the correlation with wells, we consider that it is important to carry out detailed and complete studies of the units existing in the area, in order to achieve more refined correlation.
- In general, the Cretaceous sequences, which constitute the greater part of the studied foothill, represent a monoclinal slightly sloped 25° - 35° towards NW. The folding, which affects this succession, typically represent 10° - 12° tendency towards SSW. The Sicarare fault was defined. This fault has a sinestral horizontal displacement of 7 km. Apparently, it corresponds to a fault defined in previous works as a Codazzi Fault. Starting from this last fault, various prospects have been realized based on the fact that it is a thrust fault.
- This work establishes controversy with respect to previous studies, since, for the basin, a style related to folding by thrust faults was proposed. This work

suggests that the structural style is related to the folding of the sedimentary covering with course superposed movements, which originated the only recognized regional fault.

- Two main directions of stretching were identified. The first one, most commonly expressed in diaclasses, corresponds to an axis of stretching in NE-SW direction, which is parallel to the main axis of folding and that, therefore, is associated to this deformation. The other elongation tendency has WSW-ESE direction; this last stress orientation is proposed in such way that it might be associated to compressive stress that led to the formation of the Sicarare Fault.

REFERENCES CITED IN THE ORIGINAL WORK

Aleksandrowski, P. (1985). Graphical determination of principal stress directions for slickenside lineation populations; an attempt to modify Arthaud's method. Journal of Structural Geology 7, pp. 73–82.

Allmendiger, R. (2001). FaultKin en: http://www.geo.cornell.edu/geology/faculty/RWA/

Baquero, E., Chamorro, M. & Aya, D. P. (1990). Interpretación estructural área El Paso, Subcuenca Cesar. Proyecto No. 15. ECOPETROL. Reporte interno.

Kellogg, J. (1981). Cenozoic Tectonic history of the Sierra de Perijá, Venezuela - Colombia, and adyacent basins.

Marshak, S. & Mitra G. (1988). Basic Methods of Structural Geology. Prentice Hall, 446 p.

Miall, A. (1985). Arquitectural-Element Analysis: A New Method of Facies Analysis Applied to Fluvial Deposits. Earth Science Reviews, 22, pp. 261-308.

GEOCHEMICAL SURFACE SURVEY: CESAR-RANCHERIA BASIN[1]

HIDROGEOLOGÍA, GEOLOGÍA, AMBIENTAL – HGA LTDA.

2006

INTRODUCTION

The sampling of canned gas in free space is one way of analyzing volatile compounds linked to a sample without the use of extraction by solvents. The term "headspace" refers to the free space between the upper part of the liquid or solid content and the lid of a tin can. This technique is usually referred in the pharmaceutical ambit as headspace gas chromatography, and the objective is to analyze the vapor of the substance present in the space between the level of the liquid (or solid) and the lid of a tin can.

OBJECTIVE

Acquisition of 500 soil samples and processing them by headspace gas chromatographic analysis with the purpose of detecting and quantifying light gases they contain.

LOCATION

The sampling area is located in the Cesar Department, and is surrounded by the polygon with coordinates (origin Bogotá) that are presented on Table 1.

---

[1] Estudio geoquímico de superficie Cuenca Cesar-Ranchería. HGA LTDA. Abril, 2006.

Table 1. Coordinates of polygon of the sampling area.

Vertex	NORTH (m)	EAST (m)
P1	1656000	1097000
P2	1654000	1111000
P3	1624000	1102000
P4	1569000	1102000
P5	1569000	1087000
P6	1628000	1087000

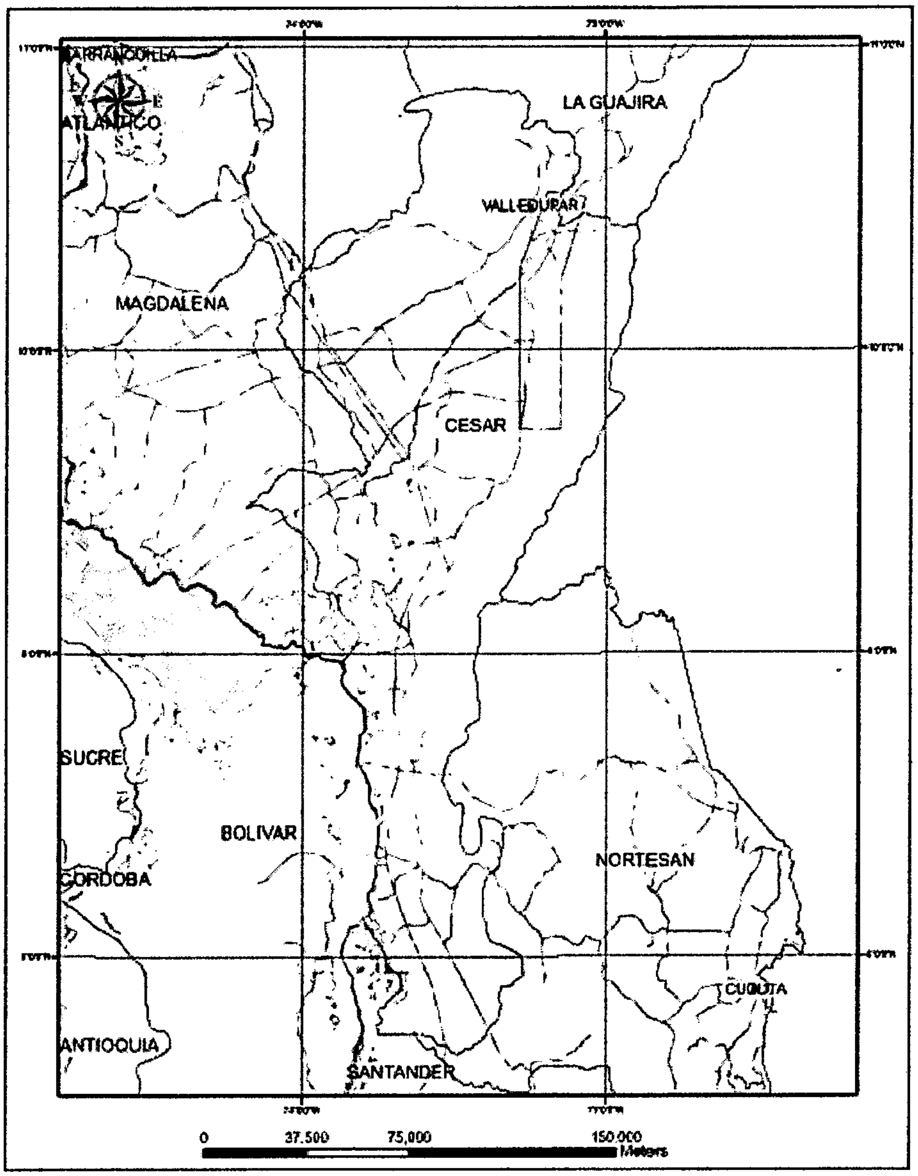


Figure 1. Location of the study area.

METHODOLOGY

The steps followed during the acquisition, processing and interpretation of geochemical data are presented as follows:

1) Sampling

- The process started with a sampling grid based on previous geological studies, which define structural characteristics of possible exploratory interest. The grid was devided by two sampling zones separated aproximately 17 km in N-S direction with 20 lines. In North Block were located 7 lines: 6 in NW-SE direction and 1 in N-S, and in the South Block 12 lines E-W and 1 N-S directions. The distance between the sampling lines is approximately 2 km and the spacing between the sampling points at each line is 500 m.
- On this grid, located sample points were consecutively enumerated, naming the first point P-1, and the last one P-500. Later on, the coordinates of each point were listed. A listing of coordinates was loaded daily on a GPS, according to the points assigned to each geologist for field sampling.
- Before starting the sampling, a stage of area recognition was carried out with the purpose of designing the sampling strategy according to the accesses. This was done in order to obtain the corresponding permits to have access to the properties involved in the sampling, to hire auxiliary personnel and vehicles and to choose the base sites.
- A manual auger was used for the drilling of holes, which have depth between 0.80 and 1.50 m and are approximately 15 cm in diameter. The end depth of the hole is determined by getting to the fresh soil layer, which allows taking the no-contaminated sample, such as possible organic matter from the upper part.
- At each sampling point, approximately 250 g of soil was gathered and put into a tin can with a perforated lid. Before closing the tin can, the sample was diluted in water, filtered and preserved by way of a bactericide in order to avoid microbial degrading of the gases. With the same characteristics, an additional

sample or safety countersample was taken, in case it would be needed to repeat the analysis or for an additional special analyses.

2) Data processing

- Chromatographic analysis of 500 gas samples obtained from soil samples.
- Determination of the composition of these gases and quantifying their concentration.
- Determination of the genesis of methane through analysis of carbon isotopes.

3) Interpretation

- Revision of results in the data table.
- Determination of Bernard's humectation index, and estimation of the type of hydrocarbon (biogenetic/mixture or thermogenetic).
- Filtering of database.
- Statistical treatment.
- Determination of the depth constant along with the first and the second order anomalous values for each one of the gasses (C1 to C5).
- C1, C2, C3, iC4, nC4, iC5 and C5 gas cartography and overlying of C2 - C5 gasses.
- Evaluation of chromatographic profiles.
- Cartography and description of areas of interest.
- Determination and plotting of relations.

RESULTS

Chromatographic analysis

For this analysis, a Hewlett Packard series 5890 II chromatograph was used, equipped with a flame ionization detector (FID) and one PLOT capillary column, having a stationary stage of alumina of 50 m length and a 0.53 mm inside diameter.

The *ChemStation* program receives and integrates the signal sent from the gas chromatograph, identifies and quantifies the concentration and shows a graphic representation of the results (chromatogram). The light hydrocarbons in the sample (methane, ethane, propane, acetylene, isobutane, butane, isopentane, pentane and hexane) were quantified according to a certified standard. The equipment was calibrated every 15 samples, and a blank sample was run every 10 analyses. The data obtained from the chromatographic analysis were organized in tables, which were used for chromatographic profiles and interpretation. The interpretation took into account the following:

Determination of the background constant and anomalies was carried out, based on statistical treatment. The obtained values are shown on Tables 2 and 3.

Table 2. Values of anomalies. North Sector.

Gas	Mean	Standard Deviation	2nd order Anomaly	1st order Gas anomaly
	μ	σ	$\mu + 2\sigma$	$\mu + 3\sigma$
Methane	15.69	13.08	41.85	54.93
Ethane	1.67	1.61	4.89	6.50
Propane	0.56	0.81	2.18	2.99
Acetylene	0.06	0.16	0.38	0.54
Isobutane	0.10	0.74	1.57	2.31
Butane	0.25	0.27	0.79	1.06
Isopentane	0.06	0.10	0.27	0.38
Pentane	0.13	0.14	0.41	0.55
Hexane	0.04	0.06	0.16	0.22

Table 3. Values of anomalies. South sector.

Gas	Mean	Standard Deviation	2nd order Anomaly	1st order Gas anomaly
	μ	σ	$\mu + 2\sigma$	$\mu + 3\sigma$
Methane	30.14*	70.21	170.56	240.77
Ethane	2.02	2.47	6.96	9.43
Propane	0.43	0.37	1.17	1.55
Acetylene	0.04	0.09	0.23	0.32
Isobutane	0.10	0.43	0.96	1.38
Butane	0.27	0.26	0.79	1.06
Isopentane	0.05	0.08	0.21	0.29
Pentane	0.13	0.11	0.36	0.47
Hexane	0.05	0.10	0.26	0.36

Once the background constant and the grade of the first and second order anomalies were defined, contour and classes maps for all the thermogenetic gasses were elaborated. Figures 2, 3 and 4 show examples of the obtained maps:

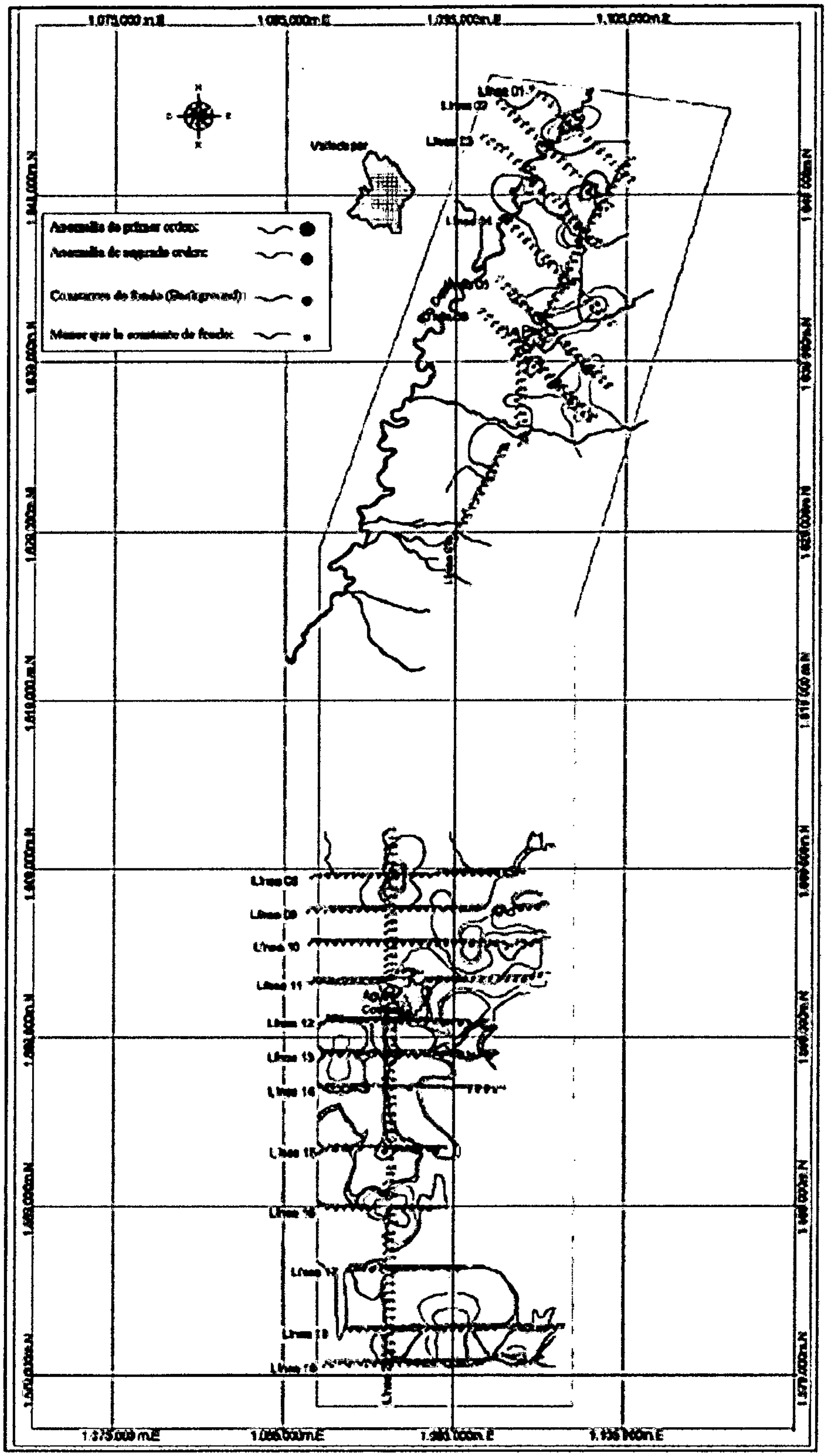


Figure 2. Map of clasess and contours of metane.

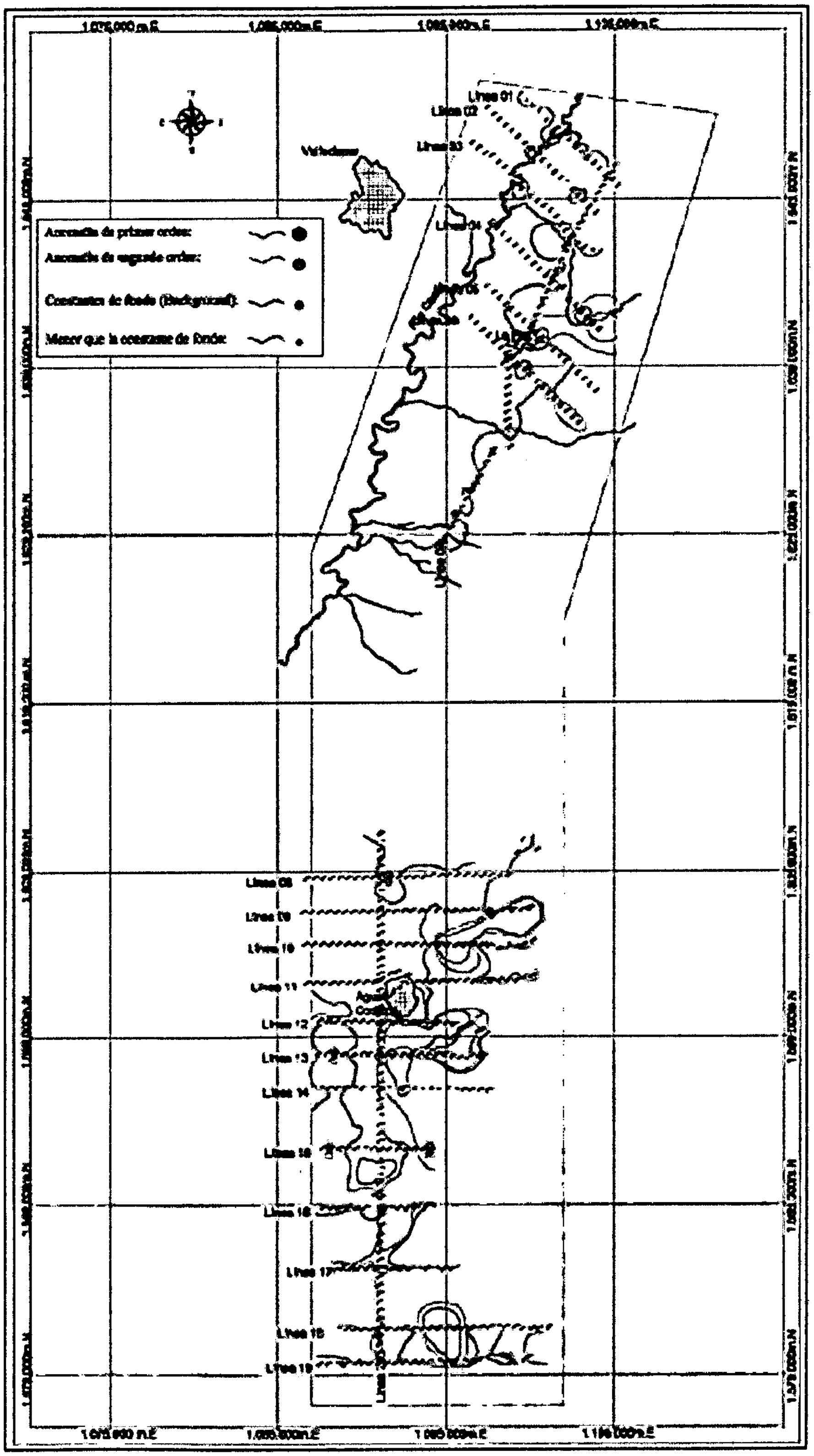


Figure 3. Map of clasess and contours of ethane.

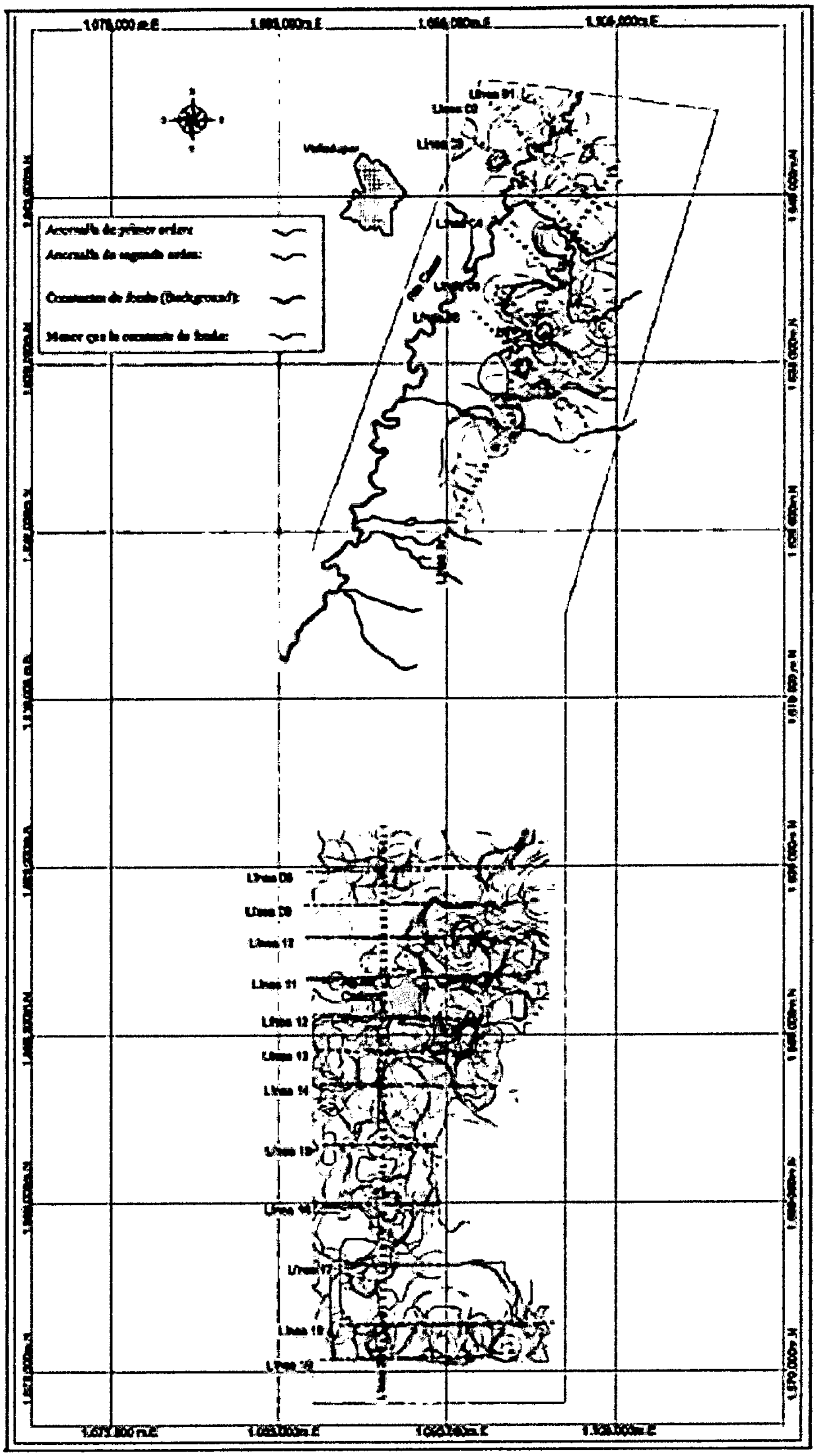


Figure 4. Map of superposition of C2 to C5 contours.

The interpretation of the chromatographic data of the soil gas samples, evaluated in the present study, allows identification of 5 groups of principaland 4 secondaries anomalies (Figure 5).

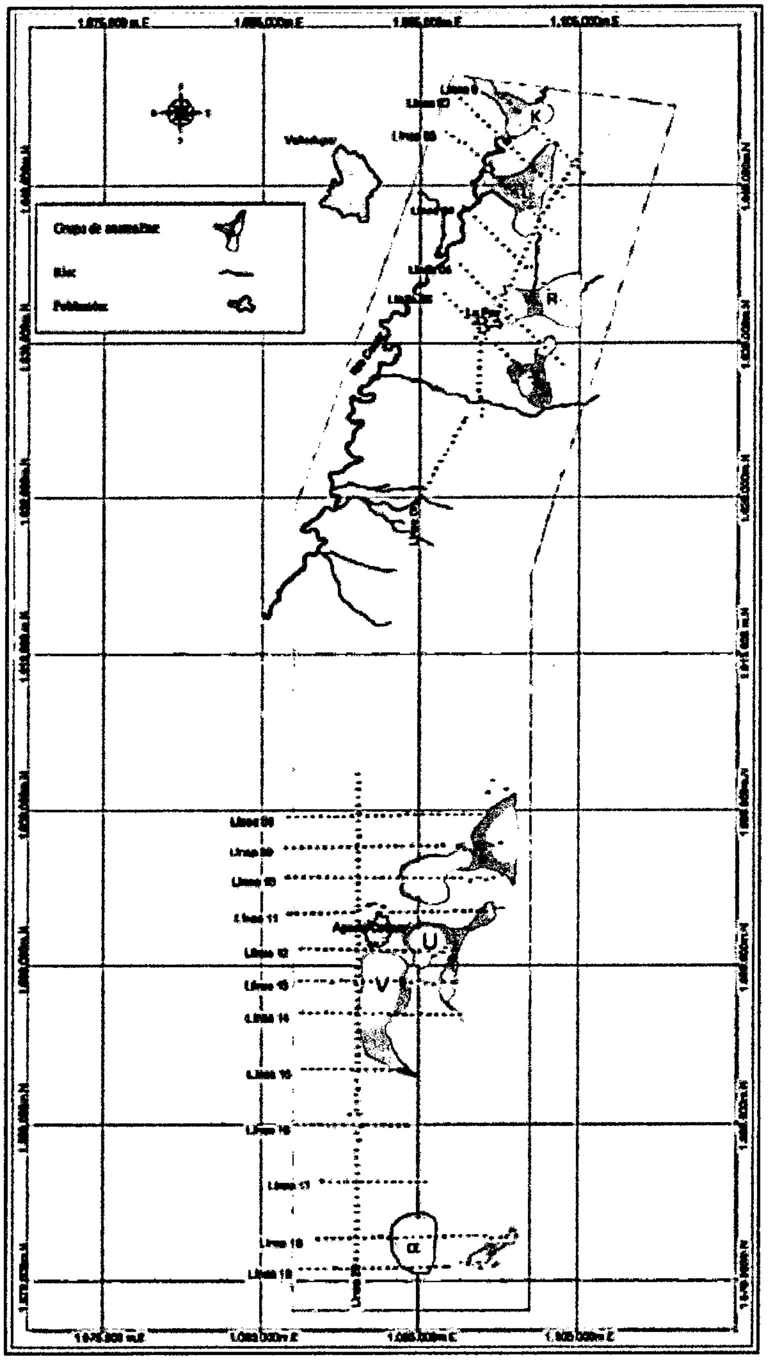


Figure 5. Map of areas of interest.

Hydrocarbons Origin

According to Whiticar (1994), the relative proportion of C1-C4 saturated alkanes within a gas sample provides an initial classification of the origin of gas. Bernard (1978), uses the C1/(C2 + C3) ratio for describing the humectation ratio, amongst others, of the surface emanation gasses and sediments and for estimation of their origin (Table 2).

Table 2. Ratio. Bernard's parameter.

Ratio (Barnard's Parameter)	ORIGIN			
	Biogenetic	Mixture	Diagenetic	Thermogenetic
C1/(C2+C3)	>1000	100 - 1000	50 – 100	0 - 50

By applying this ratio, 40 (8%) samples, amongst the total of the 500, were identified, distributed as follows: 2 (0.4%) gas samples of possible microbiological origin; 17 (3.4%) of mixture; 21 (4.2%) of possible diagenetic origin, being the rest (92%) of the samples of thermogenic origin.

Lastly, based on considerations presented by Haworth et al. (1985), it is possible to estimate that the type of fluid expected for this study area would be predominantly liquid hydrocarbon, having a minor amount of condensed and gas.

CONCLUSIONS

- The interpretation of the evaluated area in this study allows identification of 5 principal and 4 secondary areas with anomalous values of gases.
- The anomalies in the South Sector, eastern Codazzi, have a better expression.
- 92% of the 500 samples are of thermogenic origin.
- Generally, the anomalies in the Eastern Sector seem to be related with the presence of Cretacic rocks (source rocks).

REFERENCES CITED IN THE ORIGINAL WORK

Duchscherer, W., Jr., 1984, Geochemical hydrocarbon prospecting, with case histories: Tulsa, PennWell Publishing Co., 196 p.

Haworth, J. H., Sellens, M. and Whittaker, A., Interpretation of Hidrocarbons Shows Using Light (C1 – C5) Hidrocarbons from Mud – Log Data, AAPG Bulletin, V.69, No.8, 1985, p 1305 – 1310.

Krumbein W. C. and Graybill, F. A., An Introduction to Statistical Models in Geology, 1965.

Isaaks, E. H. and Srivastava, R. M., An Introduction to Applied Geostatistics, 1989.

Schumacher, D. and Abrams M. A., Hydrocarbons Migration and its Near-Surface Expression, AAPG Memoir 66, 1996.

Whiticar, M. J., Correlation of Natural Gases with their Sources, Chapter 16, en Magoon L. B. and Dow. G. W., The Petroleum System – From Source to Trap, The Petroleum System: Memoir 60, 1994.

PETROGRAPHIC AND PETROPHYSICAL ANALYSIS OF OUTCROP SAMPLES OF GEOLOGICAL CARTOGRAPHY PROJECTS: CESAR-RANCHERIA BASIN[1]

C & CO SERVICES LTDA.

www.cycoservices.com

2007

GENERAL OUTLINES

The intention of present work is to integrate the petrographic and petrophysical studies and analysis of rock samples collected during geological cartography works, stratigraphical surveys and geological control in the seismic lines of the Cesar-Ranchería Basin. The integration refers to each potential reservoir formation of the Basin.

The rock samples studied in this project mostly correspond to siliciclastic rocks and in less proportion to calcareous rocks. The evaluation of the reservoir quality in every single formation allows getting the mark from low to high, being rated the basin as of moderate quality.

OBJECTIVE

To evaluate the reservoir quality of the basin by petrographic and petrophysical analysis.

METHODOLOGY

The following analyses and parameters for each reservoir formation were integrated and evaluated:

---

[1] Análisis petrográficos y petrofísicos de muestras de afloramiento de los proyectos de cartografía geológica en: Grupo 2 Cuenca del Cesar-Rnachería. Informe Final. C&CO SERVICES LTDA. Agosto, 2007.

Petrographic: Depositional or detritus textures, diagenetical textures detritus composition or minerology, diagenetical composition or mineralogy, matrix types, cement types, porosity and pore types, porosity results (Petrograpical method or thin-section).

Petrophysical: Porosity, permeability, grain density, fluid saturation with retort.

Sedimentological: Lithofacies, lamination type or internal sedimentary structure, bioturbation and bioturbation intensity, stratigraphic column.

In order to classify the quality of the rock, the Winland correlation between porosity, permeability and the size of pore throat was applied, defining 5 categories to which different colours were assigned according to the following ranks:

Table 1. Criteria for the classification of samples by rock types

	Clasification	R35 Winland	Permeability
1	Very Goog	>8 µm	> 250 mD
2	Good	4 – 8 µm	50 – 250 mD
3	Regular	2 – 4 µm	10 – 50 mD
4	Bad	0.5 – 2 µm	1 – 10 mD
5	Very Bad	< 0.5 µm	< 1 mD

The Bioturbation levels mentioned in this report are according to the diagram shown in Figure 2.

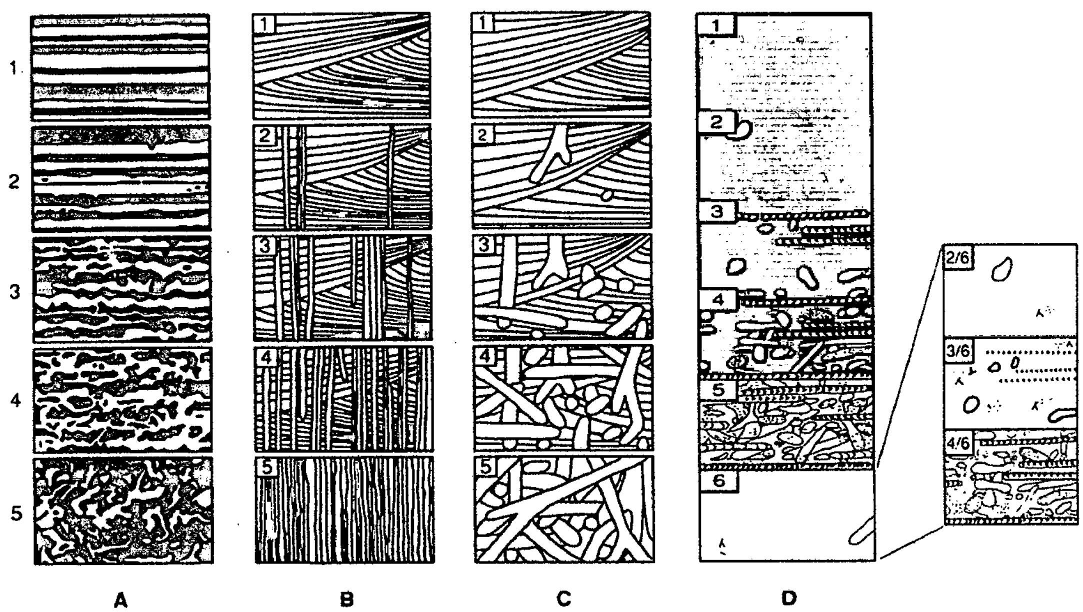


Figure 2. Schematic diagrames estimated from the bioturbation grade (ichnofrabric index). (A) Layers with thin lamination. (B) Layers with big thikness dominated by skoliths. (C) Layers with big thikness dominated by *Ophiomorpha*. (D) Deep water with fine grain environments.

A total of 183 samples were analized (Table 2).

Table 2. Analyzed samples from the Cesar-Ranchería Basin.

CESAR – RANCHERÍA BASIN		
FORMATION	**ANALYSIS**	
	PETROPHYSICS	**PETROGRAPHY**
La Quinta	3	0
Río Negro	115	44
Lagunitas	14	5
Aguas Blancas	18	4
Los Cuervos	33	9
TOTAL	**183**	**62**

RESULTS AND CONCLUSIONS

Reservoir Quality

The rock samples from the formations studied in this Project mostly correspond to siliciclastic rocks and in less proportion calcareous rocks. The evaluation of the reservoir quality in every single formation allows getting a mark from low to high, being rated this basin as of moderate quality.

The Los Cuervos Formation presents from very low to high porosity measures (1.5-20.3%) and from very bad to very good permeability (<0.003 -681mD). The best samples are located in Mina de Carbones de La Jagua Area and on the La Victoria-Becerril Road. The Río Negro Formation show from very low to high porosity measures (0.4-17.4%) and from very bad to very good permeability. The best samples (ER005) are located in Lomas Coloradas Sector; moderate values were obtained in the samples located in Candela Abajo, Cuchilla Bolembo, Sierra Fernambuco, Buenavista, Cerro Sicarare and Cerro Candela areas (LM027A, LM033, ER027, LM007, RR012 and VD011). The evaluation of the reservoir quality in every single formation allows getting a measure from low to high, being rated the basin as moderate (Figure 2).

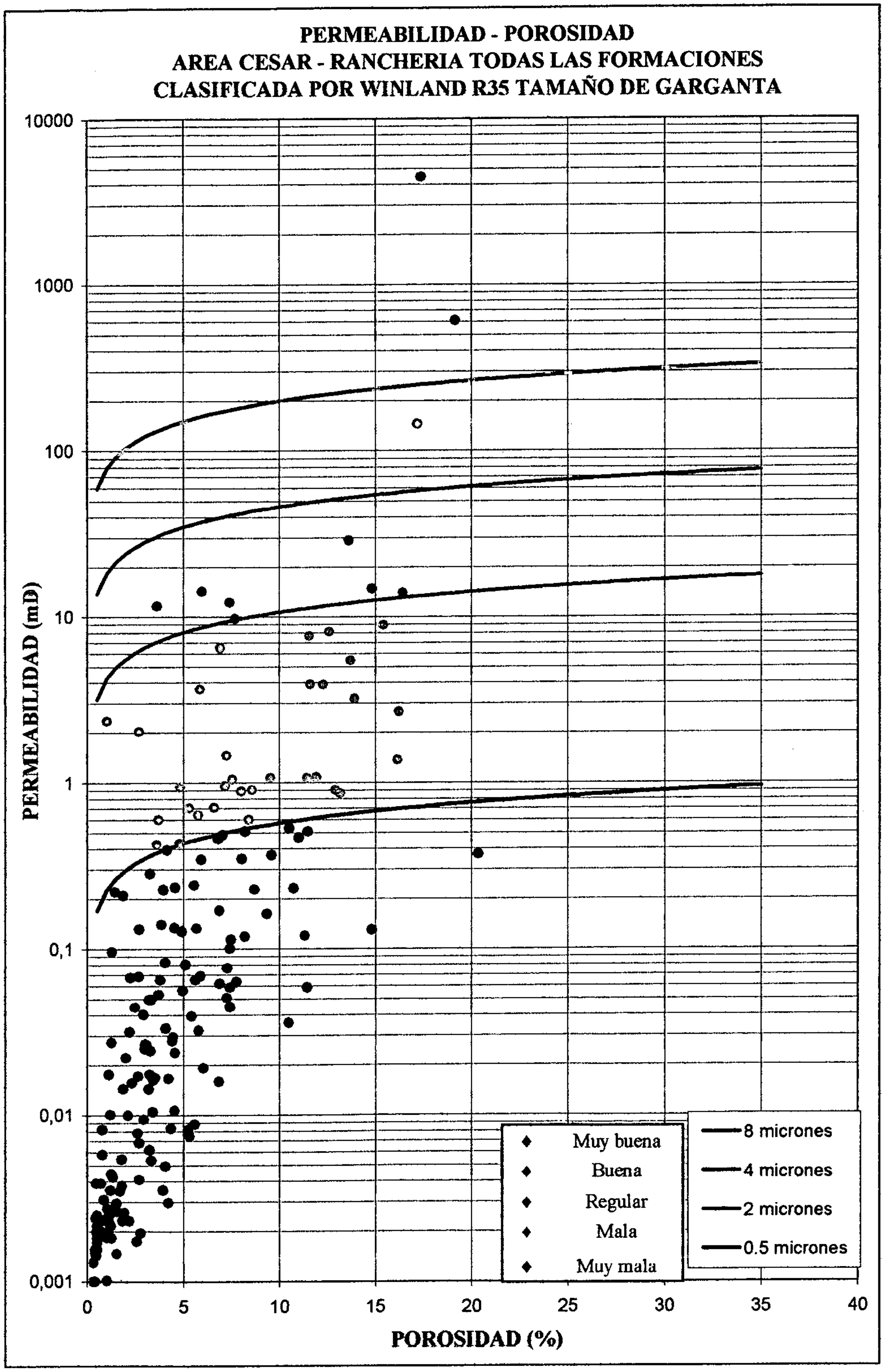


Figure 2. Porosity and Permeability of the rock samples from the Cesar-Rancheria Basin.

The reservoir quality according to the formation are shown on the Table 3.

Table 3. Reservoir quality.

FORMATION	RESERVOIR QUALITY
La Quinta	Very low
Río Negro	Moderate
Lagunitas	Low
Aguas Blancas	Low
Los Cuervos	Moderate – High

REFERENCES CITED IN THE ORIGINAL WORK

Folk, R. L. (1974). Petrology of sedimentary rocks: Austin, texas, hemphill's Book Store, 170 p.

Geostudios Ltda. (2006). Cartografía Geológica Cuenca Cesar – Ranchería.

2D SEISMIC SURVEY PROGRAM OF CESAR-RANCHERIA BASIN. INTERPRETATION AND PROCESSING FINAL REPORT[1]

UT Kpital Geofísica

2006

INTRODUCTION

This report presents the processing and interpretation of seismic data obtained as a result of the execution of 2D-reflection seismic exploration survey in the Cesar-Ranchería oil Basin, located in the northern area of the Republic of Colombia. It was planned to process and interpret 207.0 km of regional seismic lines. In accordance with the results of the processing and interpretation works, there were delivered 6 seismic lines with a 218.07 km overall volume.

LOCATION

The Cesar-Ranchería Basin, with an area of 11630 km^2, is located in the eastern part of the Cesar Department, within the mountains of Serranía de Perijá (Figure 1).

[1] Programa sísmico Cesar-Ranchería 2D. Reporte Final de procesamiento e Interpretación. Codazzi (Cesar), 2006.

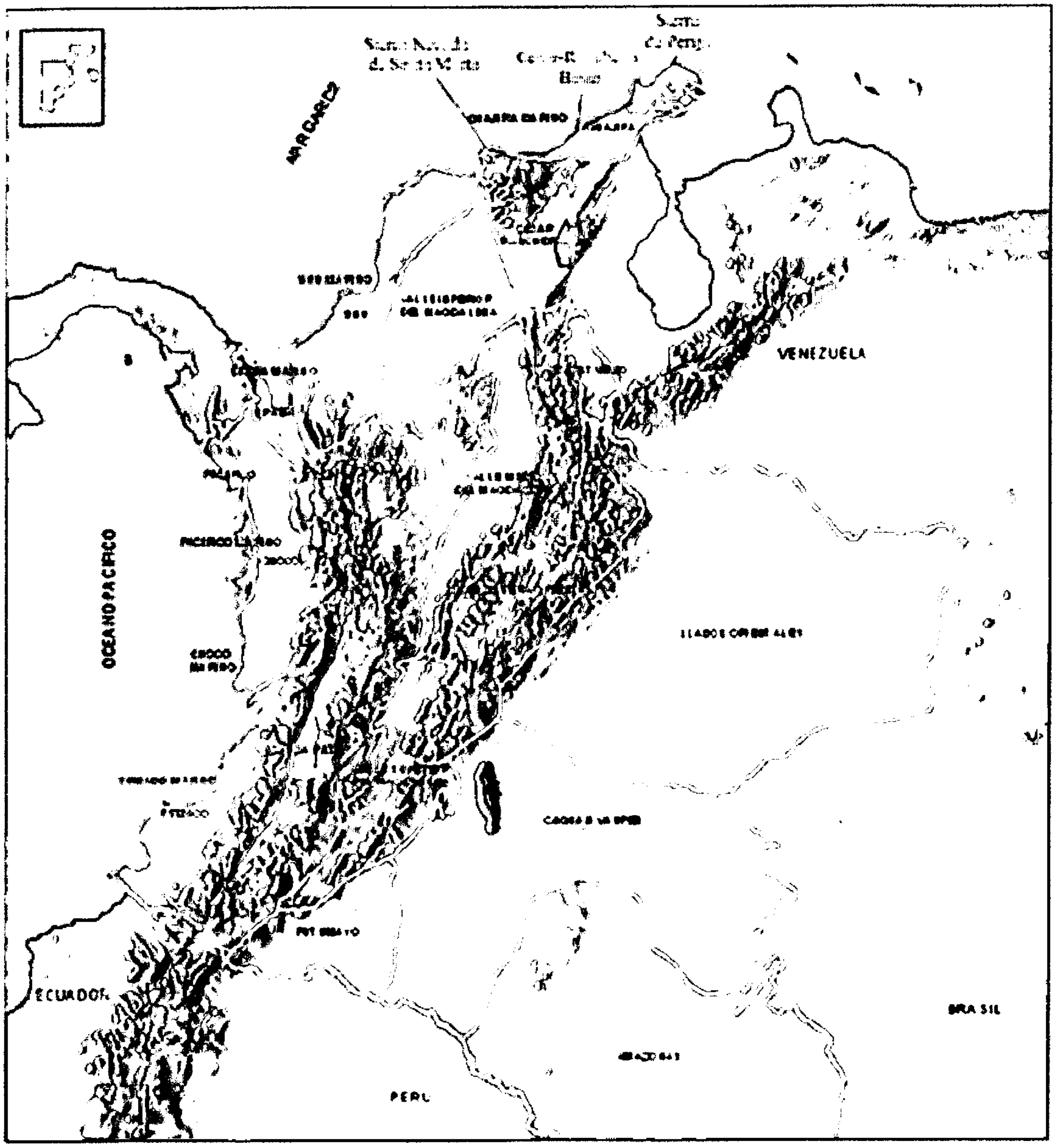


Figure 1. General map of the research area location.

Despite the long research history of Colombian gas and oil basins, its geological structure and potential oil and gas production have not been studied sufficiently. This is due to the fact that since its beginning, hydrocarbon exploration and exploitation activities have been carried out by private companies, mostly foreign ones, which did not make public the geological structure of the observed areas. A few published data are specific and isolated by nature.

The geophysical works (2D reflection seismic exploration survey) in the Cesar-Ranchería Basin were carried out during 1979-1981 and 1988-1989. The volume thereof is 700 km of 2D-reflection seismic lines. These lines are located within the limits of the Cesar-Ranchería Basin Valley and, in general, do not "reach" its mountainous area. Most of these lines were carried out in the southwestern part (the widest) of the Cesar Basin (Figure 2).

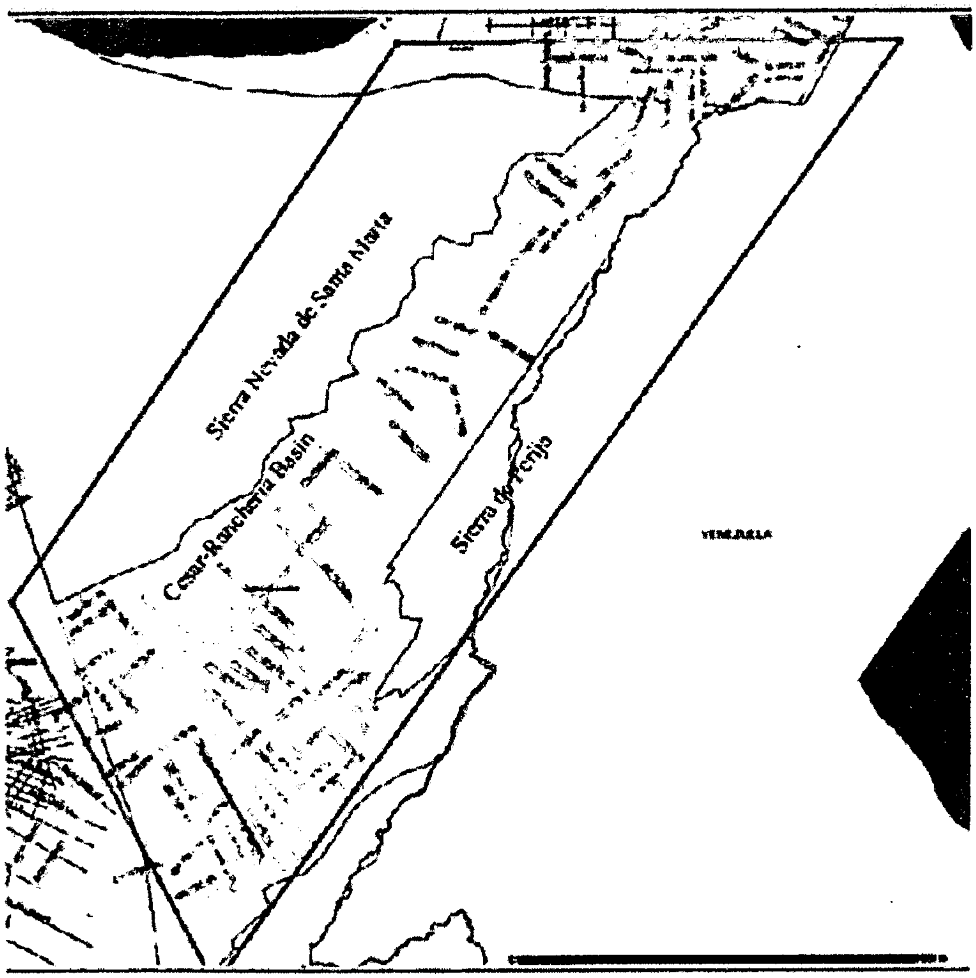


Figure 2. Scheme of 2D-refraction seismic surveys carried out in the Cesar-Ranchería Basin.

METHODOLOGY

SEISMIC DATA PROCESSING

Data Quality Control

During the data quality control process a series of technical defects were found. They occurred during the acquisition process. Among them, the following are observed in the first place:

- intermediate level of surface noise waves and mean velocity waves.
- high level of random noise in independent channels.
- excessively elevated amplitude in the channels close to the shooting point.

No more than 5% of the overall quantity of channels were excluded during the field data selection stage.

Table 1. Statistics per processed line

Line	CDP quantity	Distance, m	Number of shots
ANH-CR-2005-001	8664 (interval 10 m)	86640 m	2117
ANH-CR-2005-002	2425 (interval 10 m)	24250 m	570
ANH-CR-2005-004	2873 (interval 10 m)	28730 m	667
ANH-CR-2005-006	2715 (interval 10 m)	27150 m	642
ANH-CR-2005-008	2724 (interval 10 m)	27240 m	651
ANH-CR-2005-010	2406 (interval 10 m)	27060 m	562
Total	**21807**	**218070 m**	**5209**

Software and Equipment

The Cluster program was used as a central unit for the devices and programs complex, which comprises 8 packages and uses the PC Linux platform as its operative system. Each Cluster unit has two Intel Xeon processors with a 3.06 gigahertz frequency, 2 gigabytes operative memory, and 370 gigabytes hard drive. Access to the central calculation unit is provided through a circuit of wires with a 1 gigabyte passing capacity and 16 terminals, each one of them is adapted with an Intel Pentium 4 processor with a 3.4 gigahertz frequency, 512 megabytes operative memory, and 120 gigabytes hard drive.

parameters was made for the following processes: amplitude recovery, deconvolution, bandpass filter, coherent filtering in the sismograms of shooting points, elimination of random noise, migration, etc.

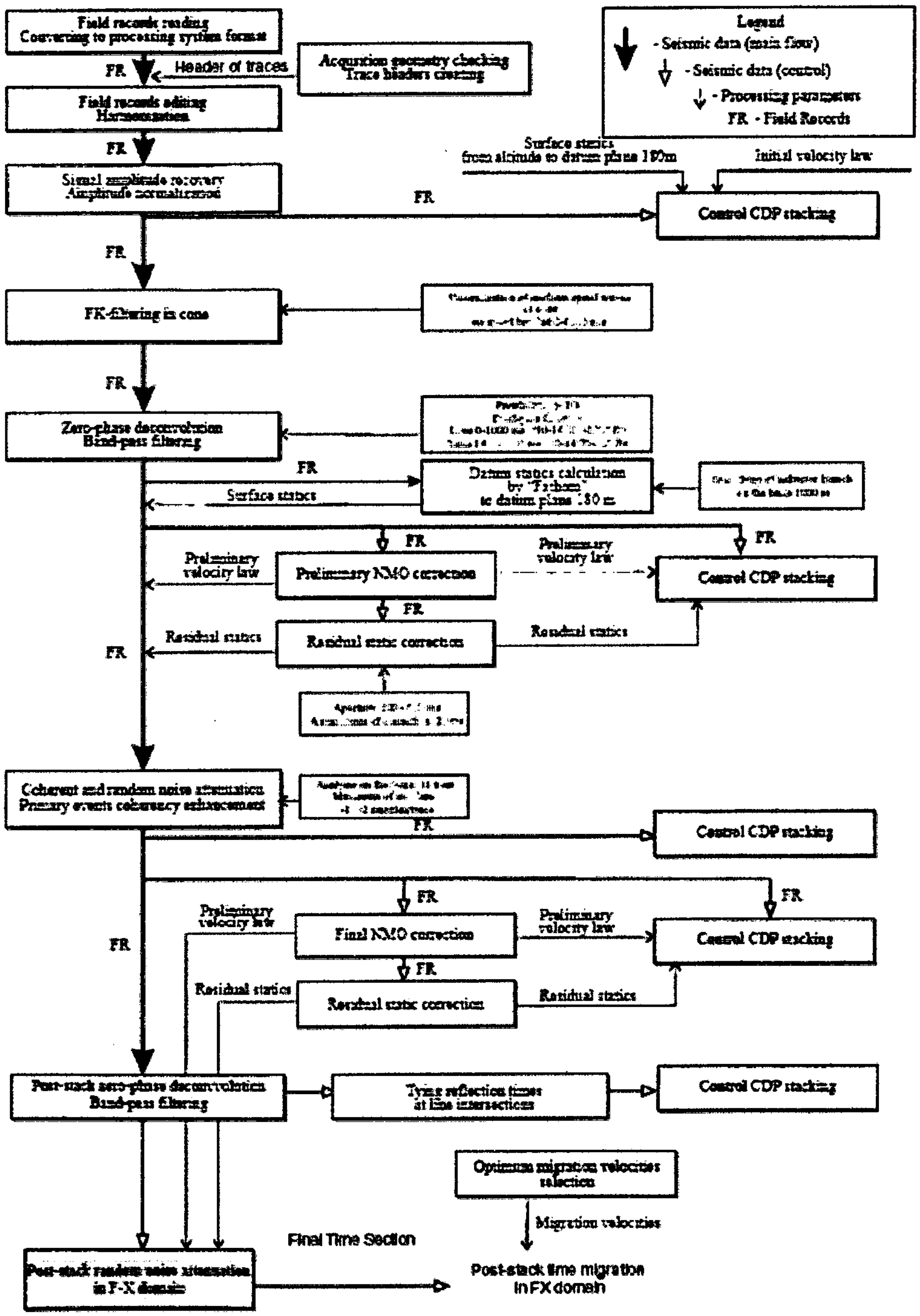


Figure 3. Basic Sequence Processing

RESULTS AND INTERPRETATION

Seismic data interpretation was carried out with the help of interpretation program "GeoGraphix" Discovery (Landmark, U.S.A.). In total, 218.07 km were interpreted. The following stages were conducted using this program:

1. Mapping of the research area, including the topography of seismic lines.
2. Horizons correlation.
3. Correlation and analysis of the area of conditional reflection horizons.
4. Mapping of isochrone according to the identified conditional horizons.

Figure 4 shows the most representative stack of the area.

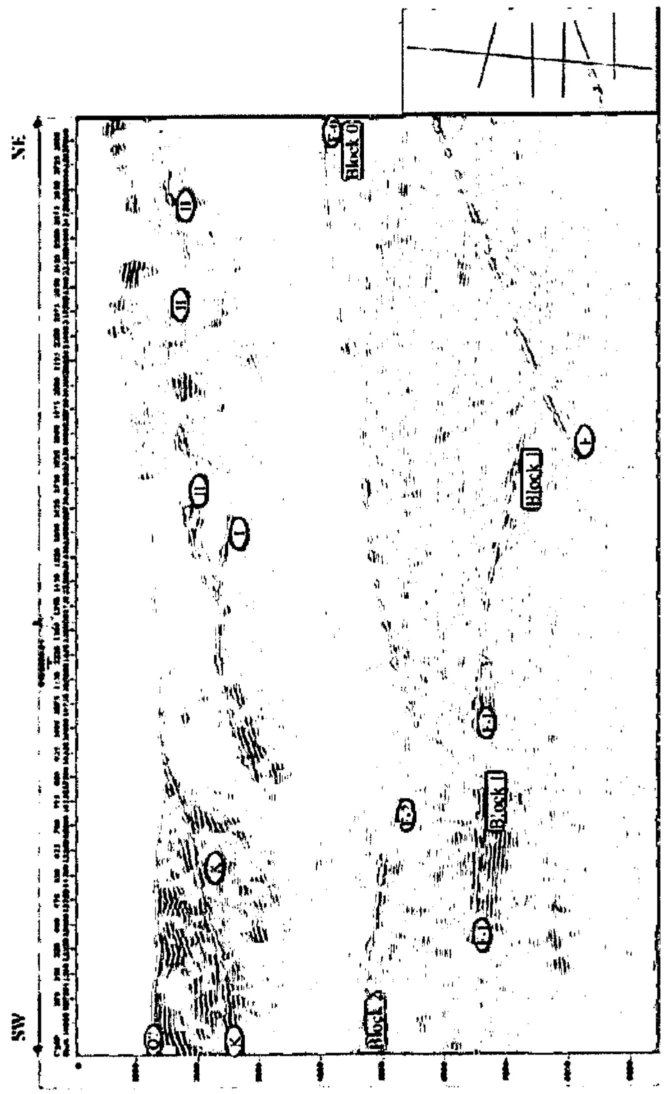


Figure 4. In Time Section of the ANH-CR-2005-04 Line.

In theese maps one of the possible geological-geophysical models of this tectonized territory is represented. This territory seems to show a thrust fault behavior of the southeastern part of the Cesar Basin with the mountainous system of Serranía de Perijá. The Basement of the study area has a block shaped structure. Isochrone mapping reflects the special attributes of the surface structure thereof, identified with the top of the Basement by three tectonic blocks: Block 0, Block 1 and Block 2.

Block 1 is related to the condicional reflection horizon K, which is the base for the Cretacic sediments. This was the only reflection horizon that was possible to correlate with the geological map. The next reflection blocks, which was posible to follow in the section, are related, possibly, with the Jurasic interior horizons. These blocks differentiate each other because their weak dynamic expression, and their sporadic continuity. These horizons are registered in a wide time interval: 3.0 to 8.2 s. The classification of the three condicional reflection horizons, corresponding to the basement surface, is sustained by their pertenence to different bocks.

REFERENCES CITED IN THE ORIGINAL WORK

García-Manjares, C. (1990). Proyecto Cesar-Ranchería. Piedecuesta, Santander. Material del Banco de Información de ECOPETROL.

Geología del petróleo, guía (1968). Tomo 2, libro 2. Yacimientos de petróleo en países extranjeros. Bajo la redacción de Visotsky. – Moscú: "Nedra".

Gurvich, I. & Boganik, G. (1980). Exploración sísmica. Ed. Nedra. Moscú.

Harton, L.; Werdington, M. & Meikin, G. (1989).Procesamiento de datos sísmicos. Traducción del inglés. Ed. Mir. Moscú.

Medina-Duarte, A. (1982). Investigación de la estructura geológica y de las perspectivas gasopetrolíferas de la cuenca Llanos (Colombia) de acuerdo a datos geofísicos. Tesis para optar por el título a Candidato a Doctor en Ciencias Geológico-mineralógicas (PH. D. en geología y Minería). Material del Banco de Información de ECOPETROL.

Prospecto de la Cuenca Cesar-Ranchería (2005). Agencia Nacional de Hidrocarburos (ANH).

Sherif, P. & Vendar, L. (1985). Exploración sísmica. Dos tomos. Traducción del inglés. Ed. Mir. Moscú.

Spencer, A. (1977). Cinturones plegados del Mesozoico y del Cenozoico (material de tectónica comparada), tomo 2 (cinturones plegados de las inmediaciones del océano Pacífico y del Caribe) traducción del inglés. Ed. Mir. Moscú.

PROSPECTIVITY OF THE CESAR-RANCHERÍA BASIN[1]

Universidad Industrial de Santander

www.uis.edu.co

2007

SUMMARY

This work features the aspects of regional geology and that of the basin, such as tectonic and structural evolution. The stratigraphy of the basin is precisely described, including its depositional environment, its sedimentological evolution and the hydrocarbon potential. After defining regional and local geological aspects, tectonic evolution and stratigraphy, a chronological summary of the exploratory activity in the basin is established indicating the obtained results. Afterwards, the summarized gravimetric, seismic, geochemical and borehole data available in the basin are presented.

Based on the previous data, a seismic interpretation is elaborated, including the respective structural maps of the selected horizons. This work features the following petrophysical data: the one that was used and another one, elaborated in two boreholes on three formations in each one. With the seismic interpretation, the boreholes data and basic geochemical data, a geochemical model 1D and 2D was elaborated for each one of the sub-basins.

[1] Prospectividad de la Cuenca Cesar-Ranchería. Universidad Industrial de Santander. 2007.

Finally, the chapter denominated as final evaluation was written out, where all the previous data are integrated and all the prospects with their respective calculation of resources are defined from three scenarios: low, normal and high.

LOCATION

The Cesar-Ranchería Basin is located in extreme northeast of Colombia, along the Venezuelan border. Geographically, it belongs to the Cesar and Guajira Departments and has an approximate area of 11630 km^2 (Figure 1).

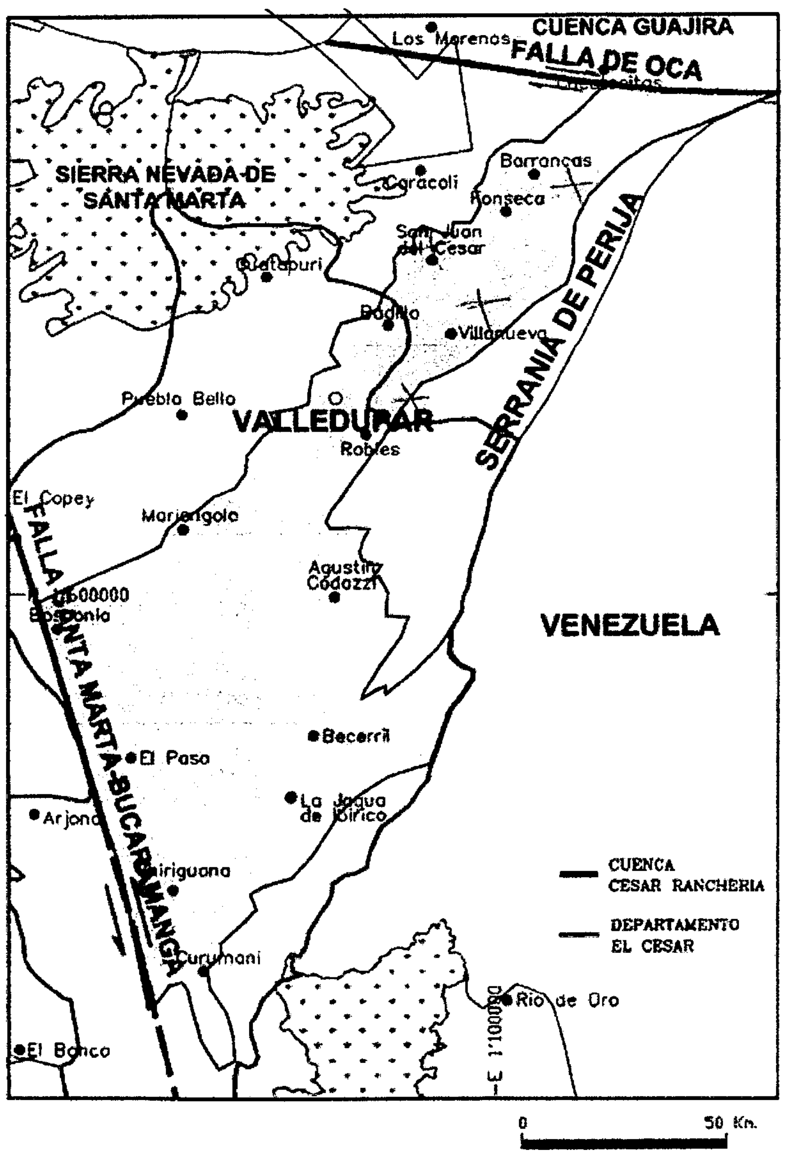


Figure 1. Location map of Cesar-Ranchería Basin.

The Basin is located between the Santa Marta Massif to the northeast and the Perija´s Ridge to the east-northeast, in its occidental margin are situated the Cerrejon and Perija faults. The Oca Fault is to the north and the Bucaramanga – Santa Marta Fault is to the west (Figure 2).

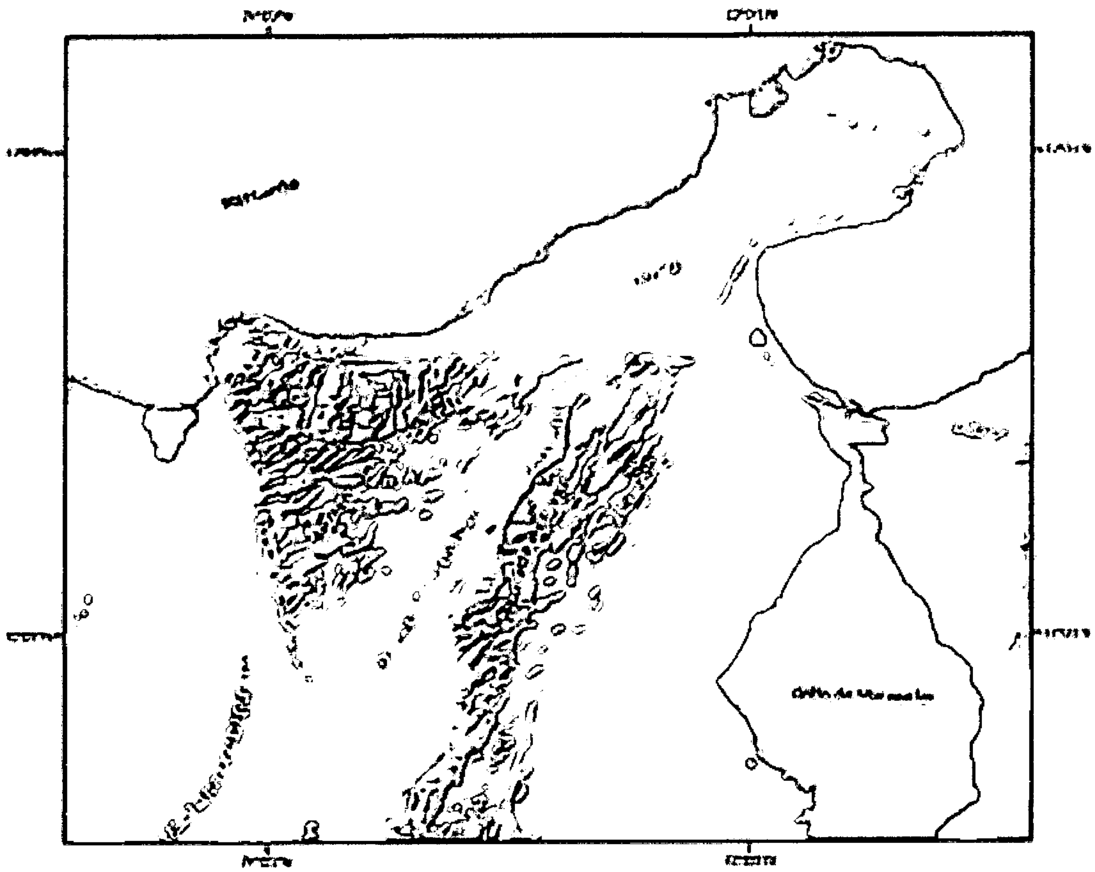


Figure 2. Regional tectonic Frame.

GENERAL OUTLINES

Structural Geology

The subduction of the Caribbean Plate under the Southamerican Continent generated a compressive stress towards the southeast, while the collision and underthrusting of the north of the Santander Massif border by the Andean movement was towards northeast. Adding the barrier stress done by the Guyana Shield located to the southeast, they generated a compressive stress in the north direction (Figure 3).

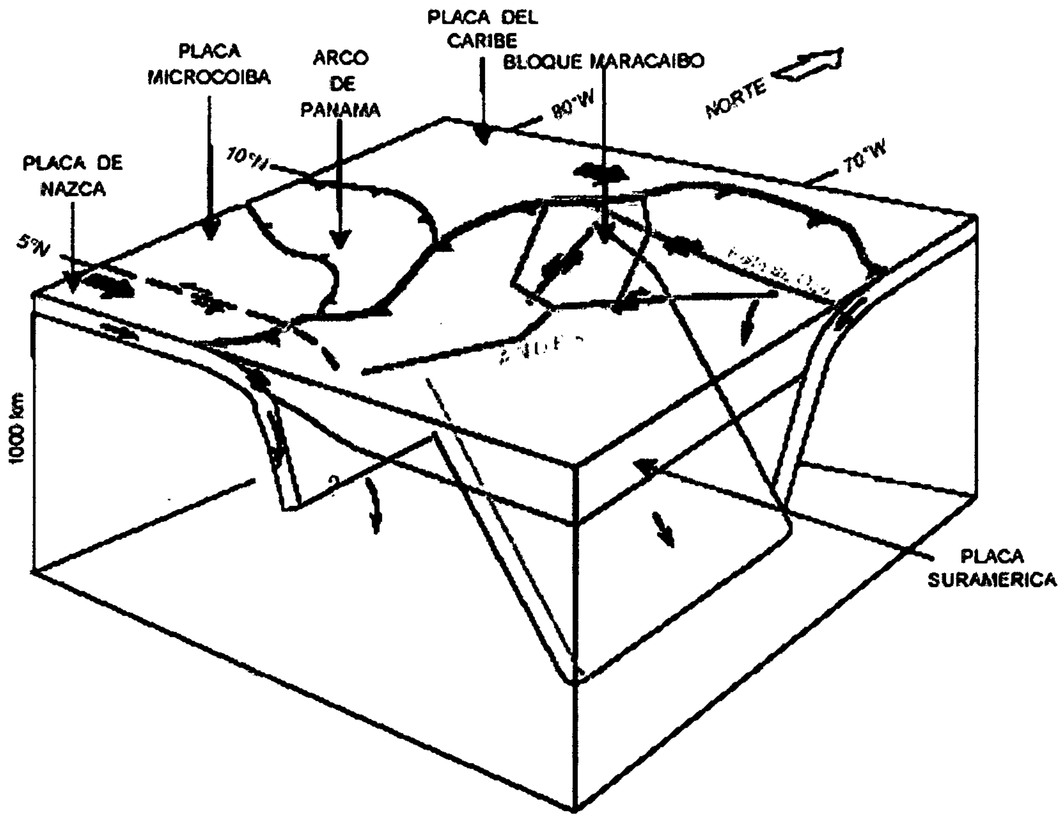


Figure 3. Block 3D, tridimensional geometry and cinematics of actual subduction.

Tectonic aspects

The development of the Cesar–Ranchería Basin since the post-Triasic can be summarized in the following steps:

1. The extensional Jurassic faulting rift formation, located in Cesar, in the occidental sectors of Ranchería and in the Perija´s Ridge.

2. One thermal subsidence occurred during the early to medium Cretacic, developing thick "post-rift" mega sequence separating from the passive margin of the proto-Caribbean by the Sierra Nevada de Santa Marta Block developed during the Mesozoic.

3. In the Oligocene, there was compression and thrust inside of the Cesar-Ranchería Basin, as well as in west margin of the Perija´s Ridge. As a consequence there is thrust of the Cerrejon Formation.

4. Thrust course during the Pliocene and development of Santa Marta and Oca faults. In general, the faults reactivation and intensive erosion of all the structural elements characterize the Pliocene history in the region.

Stratigraphy

The rocks presented in the basin comprise since Precambric until recent deposits. This project describes the single pieces presented in basin, specifying their age, thickness, contacts, deposit environment and correlation. This work provides general analysis of sequences, indicating the principal events of fall and rise of the base level in the basin. Given the previous data, the present project establishes the sedimentologic evolution of the basin. Moreover, due to the interest in the area because of hydrocarbons presence, this work presents a summary of characteristics of the formations regarding organic material, generation potential, accumulation potential, seals and possible types of generated hydrocarbons.

The characteristics of the rocks in the basin, starting from the Precambric, are shown in the generalized stratigraphic column, by using the Figure 4 as a reference.

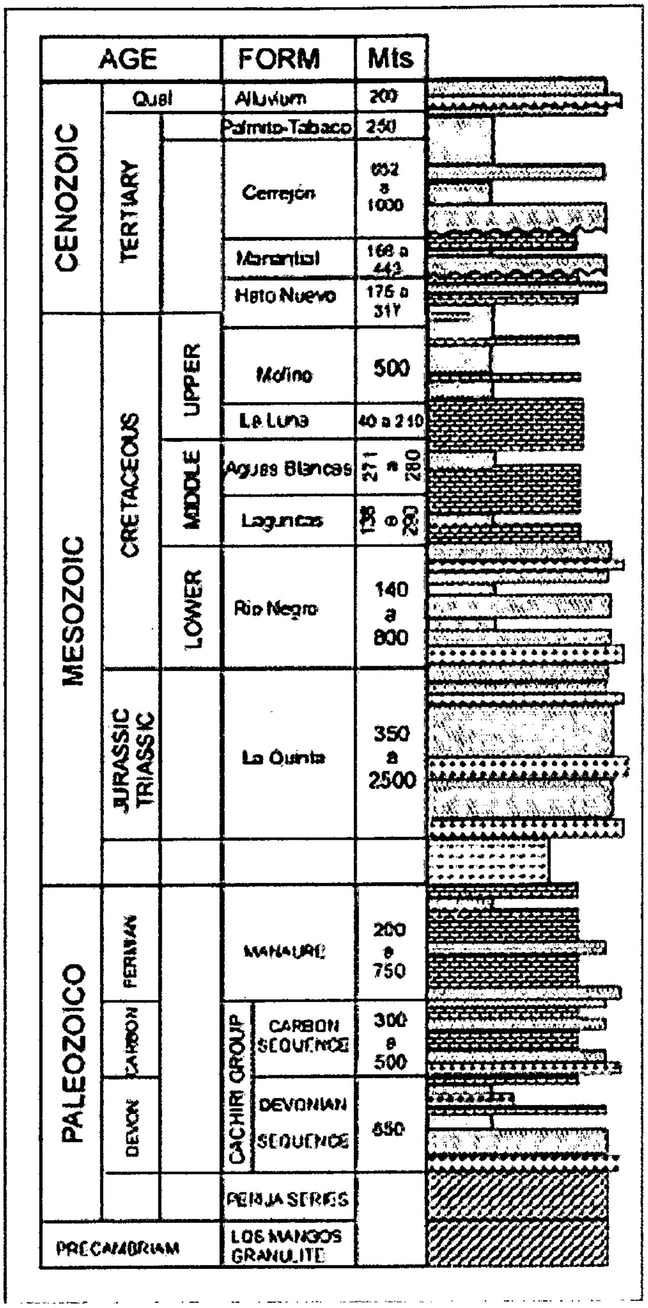


Figure 4. Generalized stratigraphic column Cesar-Ranchería Basin.

Potential of Hydrocarbons

In Tables 1 and 2 the potential of hydrocarbons of the Cesar-Ranchería Basin is resumed, indicating the content of organic material, the potential of generation, the potential of accumulation, the possible types of hydrocarbons to find and the characteristics as a seal, of the formations presented in the Cesar Sub-Basin and in the Ranchería Sub-Basin.

Table 1. Oil-bearing potential of the formations presented in the Cesar Sub-Basin. Cesar-Ranchería Project. (ECOPETROL 1998).

FORMACIÓN	CONTENIDO DE MATERIA ORGÁNICA	POTENCIAL DE GENERACIÓN	POTENCIAL DE ACUMULACIÓN	POSIBLES TIPOS DE HIDROCARBUROS	SELLO
BARCO CUERVOS	Muy alta en forma de materia orgánica húmica	Regular a buena, buena madurez, rata de enfriamiento moderado a alta	Buena en areniscas principalmente hacia la base	Gas seco condensado. Aceite liviano	Buena por espesor de la formación y presencia de arcillas
MOLINO	Buena en forma de materia orgánica exinítica	Alta. Buena madurez geotermal. Moderada a alta rata de enterramiento	Baja a moderada. Pocas rocas acumuladoras (Areniscas y Calizas)	Gas seco condensado. Aceite liviano	Bueno a excelente
LA LUNA	Alto en la forma de materia orgánica alginítica	Buena. Alta madurez y alta rata de enterramiento	Alta, principalmente en fracturas	Condensado. Aceite liviano	Regular
AGUAS BLANCAS	Moderada en la forma de Materia orgánica exinítica	Alta. Excelente madurez geotermal y alta rata de enterramiento	Moderado, únicamente en fracturas, buena en areniscas del Miembro Tocuy	Aceite liviano	Regular
LAGUNITAS	Bajo a moderado	Bajo a moderado	Moderado, únicamente en fracturas	Aceite semi-pesado	Regular
RÍO NEGRO	Muy bajo	Casi nulo	Moderado en areniscas	Aceite semi-pesado	Regular
LA QUINTA	Muy baja a nula	Nula	Moderada en rocas volcánicas fracturadas o areniscas	Aceite pesado	Malo
GP CACHIRÍ	Bajo a medio	Baja a muy baja. Materia orgánica sobremadura	Baja, únicamente en fracturas (calizas), medio en areniscas	Gas térmico	Regular

Table 2. Potential oil-bearing of the formations presented in the Ranchería Sub-Basin. Project Cesar Ranchería. (ECOPETROL 1998).

FORMACIÓN	CONTENIDO DE MATERIA ORGÁNICA	POTENCIAL DE GENERACIÓN	POTENCIAL DE ACUMULACIÓN	POSIBLES TIPOS DE HIDROCARBUROS	SELLOS
TABACO	Muy bajas	Nulo (Inmaduro)	Bajo	Ninguno	Malo
CERREJÓN	Muy alta (Materia orgánica húmica)	Regular a buena	Buena en areniscas (principalmente hacia la base)	Gas seco (metano) condensado	Regular a bueno
HATO NUEVO MANATIALES	Baja	Baja. Falta de madurez termal	Moderado principalmente en calizas fracturadas	Gas seco	Mala a regular
MOLINO	Buena	Madurez geotermal baja. Moderada rata de enterramiento	Muy baja. Pocas rocas acumuladoras (areniscas)	Gas seco condensado	Buena a excelente
LA LUNA	Alta	Madurez geotermal baja	Alta. Principalmente en fracturas	Condensado. Aceite liviano	Regular
GP COGOLLO	Moderada	Alta, Buena madurez geotermal y alta rata de enterramiento.	Moderado, únicamente en fracturas	Aceite liviano semi-pesado	Regular
LA QUINTA	Muy bajo	Casi nulo	Moderado , en rocas volcánicas fracturadas y en areniscas	Aceite pesado	Malo
MANAURE	Baja	Bajo a muy bajo. Materia orgánica madura a sobremadura	Moderado, únicamente en fracturas	Gas húmedo	Regular
GP CACHIRÍ	Bajo a moderado. Materia orgánica carbonáceas	Moderado, materia orgánica madura a sobremadura	Baja a muy baja en fracturas	Gas húmedo	Bueno

Gravimetric Data

On the Figure 5, the map of Bouguer Anomaly for the studied region is shown. It is possible to observe a big difference of density in the NW-SE direction, which is greater in the Sierra Nevada de Santa Marta (140 mGal), the Valle del Cesar oscillate between 20 – 30 mGal, and the Perija´s Ridge between 0 – 20 mGal, considering that the Sierra Nevada de Santa Marta and Perija´s Ridge are topographic highs. The zone of negative anomalies is associated with accumulation of sediments. There is a transition zone among the negative and positive anomalies, which may indicate a mayor slope of the basement rock, which implies a reduction of the sedimentary column or thickness of the basin. Finally, in the zone of positive anomalies there is a difference of values that can suggest a change in the character of the sediments or a structural change.

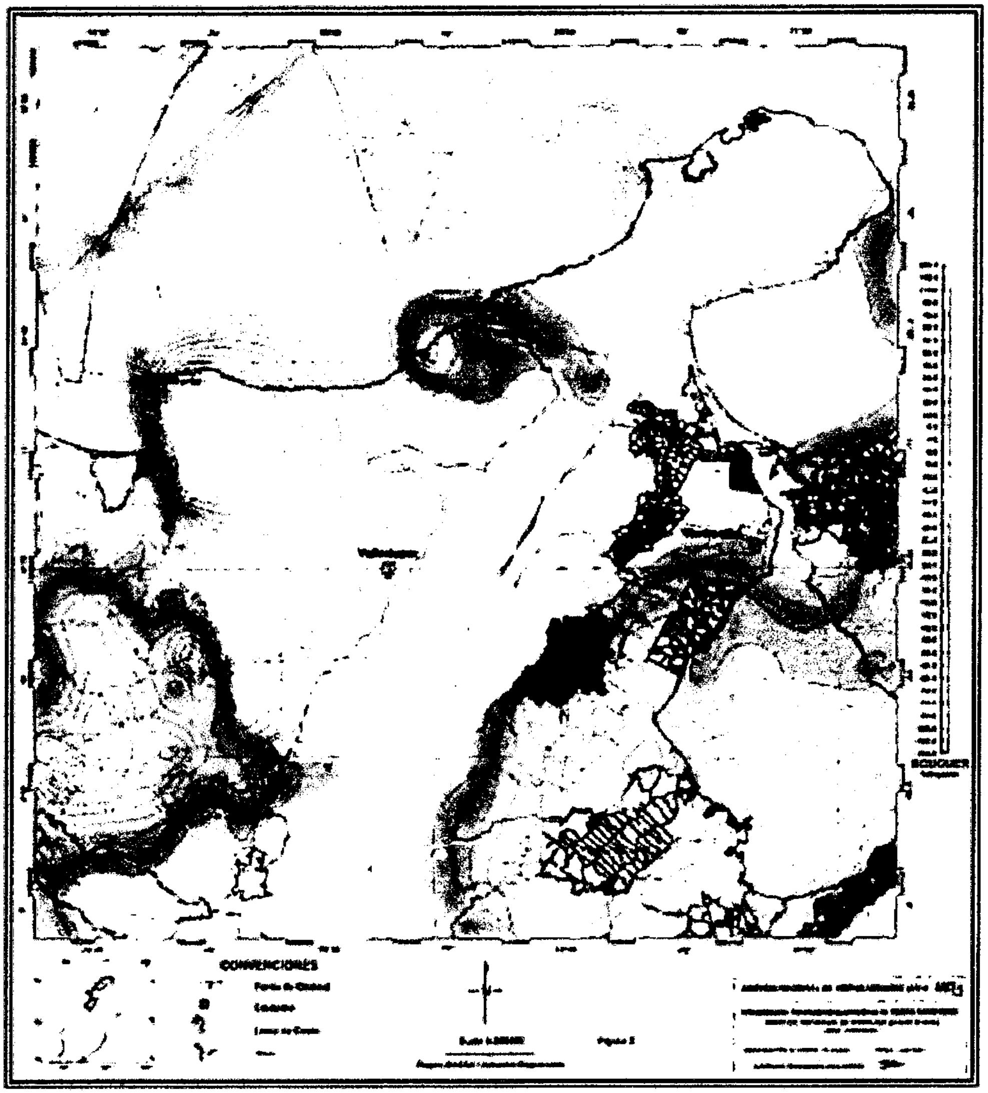


Figure 5. Bouguer Anomaly Cesar-Ranchería Basin.

Figure 6 shows the map of gravimetric interpretation of the Cesar-Ranchería Basin controlled residual base of the Tertiary. On this image the prospective areas are observed, outlined along the Ranchería Sub-Basin, located in its northern part.

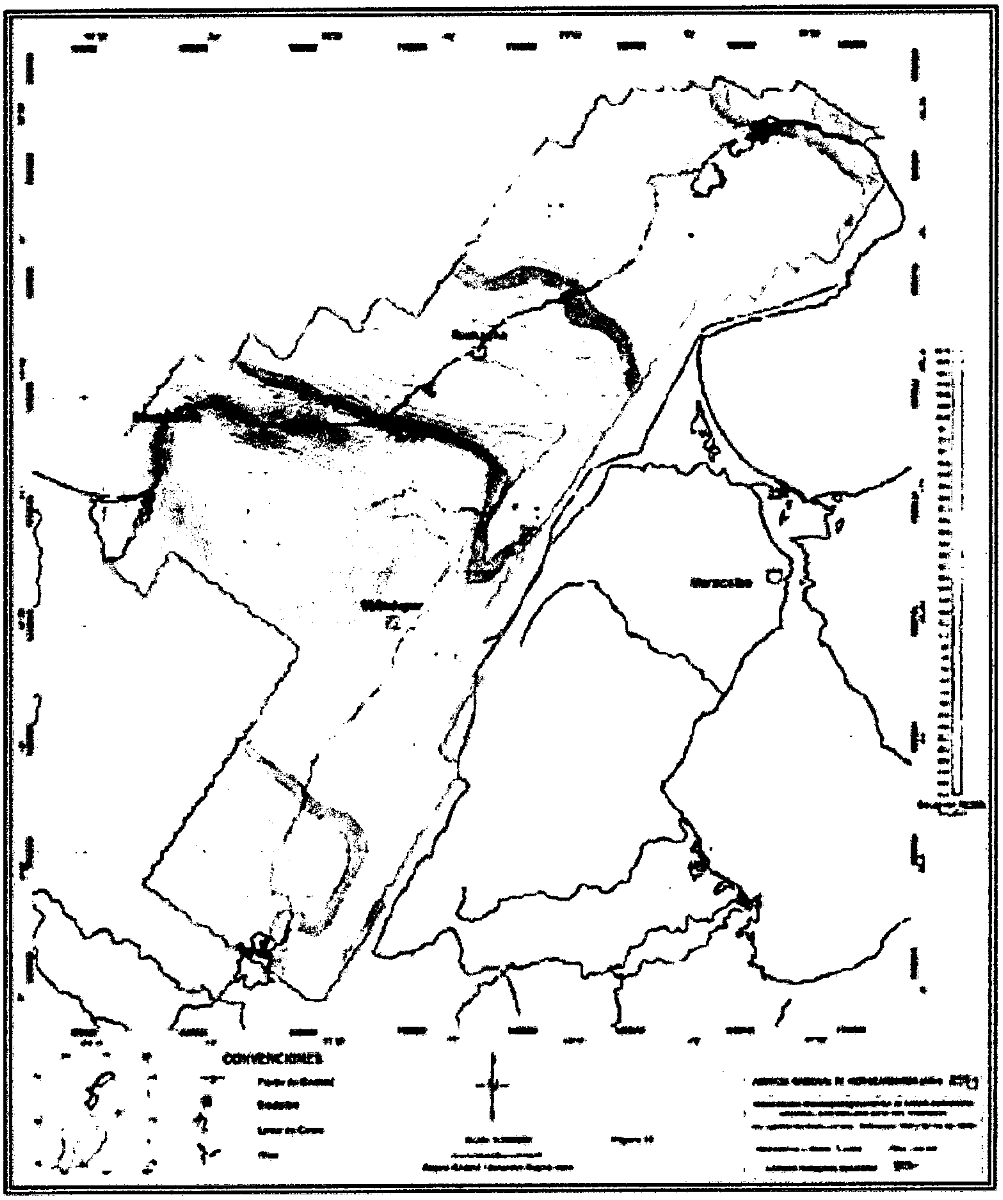


Figure 6. Aerogravimetric interpretation of the Cesar-Ranchería Basin controlled residual base of the Tertiary.

Seismic data

The Tables 3 and 4 resume the general characteristics of the seismic programs realized in the Cesar-Ranchería Basin from 1979 until 2005.

Table 3. General Parameters for seismic program. Cesar Sub-Basin Source: Project Borders Basins. Report of Data Compillation. ECOPETROL 1990, Report of Seismic processing. Program las Nieves 2D 2000. Area La Loma Cesar (Colombia). Llanos Exploration Colombia LTD. 2002.

Progr. Sismico	Regis. Para	Regis. Por	Long(Km.)	Calidad	N° de Líneas Sismicas	Resol. Vertical	Resol. Horizont
Valle del Cesar CV-79	Phillips Petroleum	GSI	1904	Regular	49	Moderada	Moderada
Mompos 81	Gulf Oil. Co	GSI	285	Buena	21	Moderada	Pobre
Guajira Cesar CR-88	Ecopetrol	Geosource	292	Buena	14	Moderada	Moderada
Las Nieves 2D 2000	Llanos Oil Exploration LTDA.	Sismopetrol	69	Buena	6	Moderada	Buena
ANH 2005	ANH	UT KPITAL Geofísica	182	Buena	6	Buena	Buena
La Loma 2D 2005	Drummond	Drummond	32	Buena	9	Buena	Buena
TOTAL			**2764**		**105**		

Table 4. General Parameters per seismic program. Ranchería Sub-Basin Source: Project Borders Basins. Report of Data Compillation. ECOPETROL.1990, Seismic Report. Programs Processing: Villanueva North-88, Guajira-90, Maicao-90. Guajira – Cesar Area. Colombia. ECOPETROL 2002, Geological Interpretation of the Seismic Data of the Ranchería Sub-Basin. ECOPETROL.1991.

Prog. Sismico	Regis. Para	Regis. Por	Long (Km.)	Calidad	N° de Líneas Sismicas	Resol. Vertical	Resol. Horizont
Ranchería CR-79	Ecopetrol	Western	492	Moderada	10	Moderad a	Pobre
Guajira Cesar CV-88	Ecopetrol	Geosource	156	Moderada	12	Moderad a	Moderada
Sierra Perija CP-88	Ecopetrol	GSI	98	Pobre	6	Pobre	Pobre
Guajira Cesar CV-89 (Perija)	Ecopetrol	Western	270	Buena	11	Moderad a	Moderada
Sorpresa 2D	Ecopetrol	Western	240	Buena	10	Moderad a	Buena
Guajira Cesar VNS - 88	Ecopetrol	GSI - Digicon	87	Moderada	8	Moderad a	Moderada
TOTAL			**1204**		**58**		

In addition, a reprocessing of the seismic program ANH 2005 was carried out, which consisted in diverse activities in order to improve the quality and the resolution of the lines of this program. In general, the seismic data is of moderate quality, with very few events observable in the whole register. The relation signal-noise is acceptable, first arrivals are well defined. The preliminary seismic interpretation presents 4 cartographed horizons (see Table 5 and Figure 7).

Tabla 5. Previously cartographed Horizons in the Cesar Sub-Basin. Source: Potential Oil-bearing **Cesar-Ranchería Basin. ECOPETROL 1998.**

"Brown" Horizon	Nonconformity of the Eoceno
"Blue" Horizon	Top limestones (Socuy Member and La Luna Formation)
"Orange" Horizon	Top Maracas Member (Aguas Blancas Top Formation)
" Green" Horizon	Top Lagunitas Formation

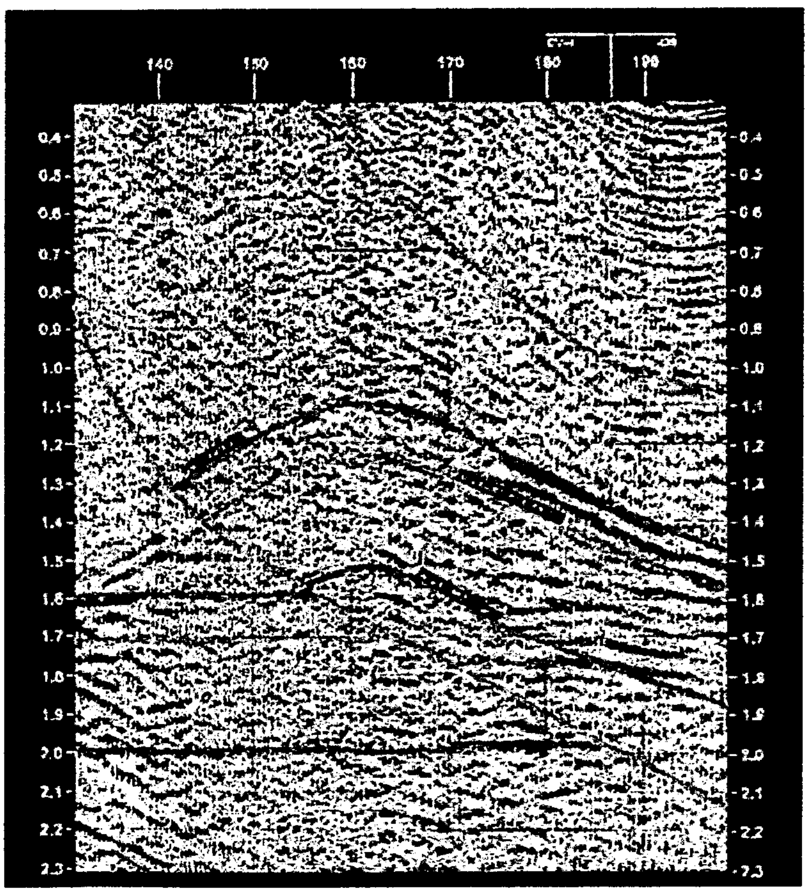


Figure 7. Seismic section CR – 88 – 1620E. On this figure the horizons described in Table 5 are clearly distinguished. Source: Potential Oil-bearing Cesar-Ranchería Basin. (ECOPETROL 1998).

The interpretation of the structures presented on these horizons, suggests the presence of 11 prospective structures, grouped in 6 areas (Table 6).

Tabla 6. Previous prospective areas in the Cesar Sub-Basin. Taken from Potential Oil-bearing Cesar-Ranchería Basin. ECOPETROL 1998

PROSPECTIVE AREA	STRUCTURE	SEISMIC LINES
Compae	Compae La Miel	CV-79-01
Santa Teresa	Santa Teresa	CV-79-03 CR-1620E
Candela	Candela El Descanso	CV-79-14 CV-79-05 CV-79-08
Casacara	Casacara Marchena	CV-79-7 CV-80-47
Becerril	Becerril	CV-79-37-PT2
Tucuy	Tucuy La Jagua Las Piñas	CV-79-39 CV-79-26
Lead 1	El Paso	GM-81-07
Lead 2	Jobito	CV-79-10

In the Ranchería Sub-Basin, the same procedure was carried out, cartographying the horizons mentioned in Table 7 and shown in Figure 8.

Tabla 7. Previously cartographed Horizons in the Ranchería Sub-Basin. Source: Potential Oil-bearing Cesar-Ranchería Basin. (ECOPETROL 1998).

Horizon "Light Rose"	Nonconformity Base of the Mioceno
Horizon "Yellow"	Conjunto Calcareo (Reef Growth)
Horizon "Brown"	Nonconformity of the Eoceno
Horizon "Light Blue"	Top Limestones (Member Socuy and La Luna Formation)
Horizon "Magenta" (purple)	Tope Cogollo Group
Horizon "Red"	Base of the Cretacic.

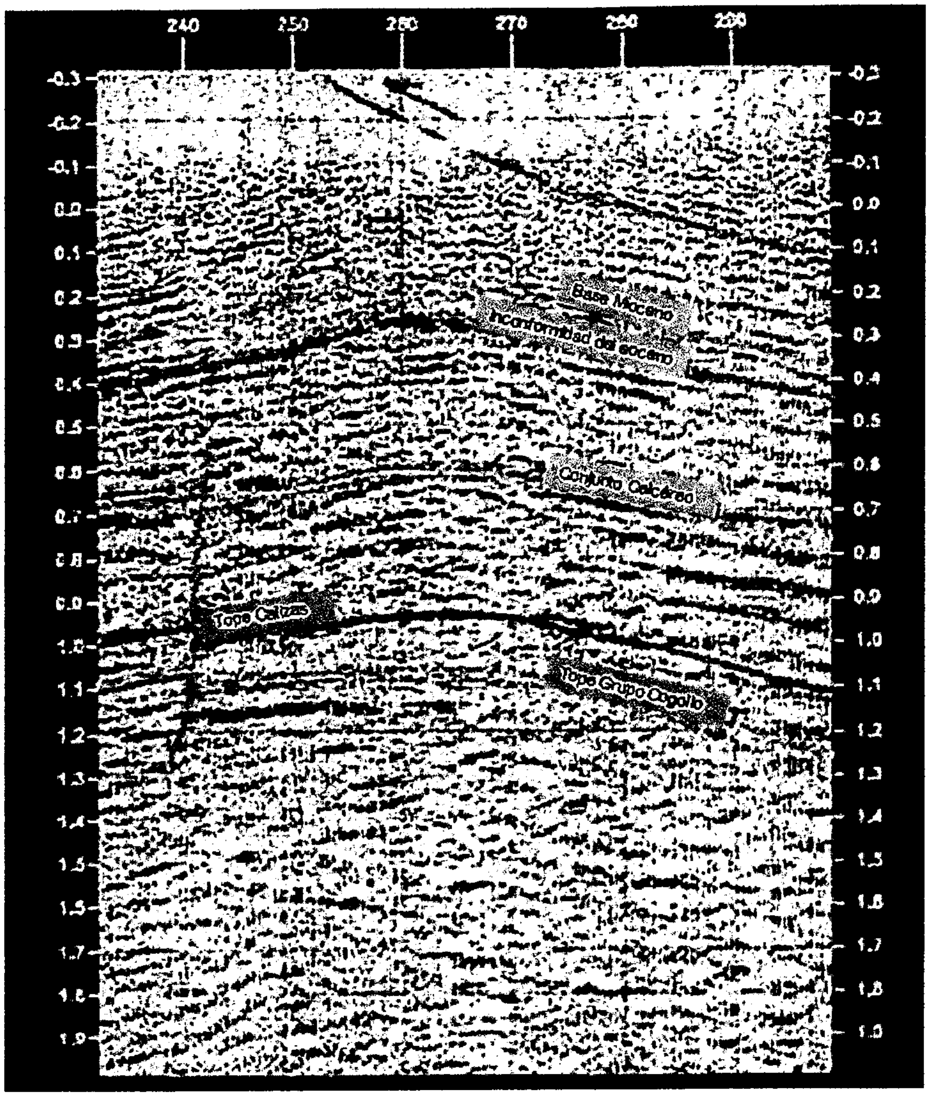


Figure 8. Seismic section CV – 88 – 1670. On this figure the horizons described in Table 8 are clearly distinguished. Taken from Potential Oil-bearing Cesar-Ranchería Basin. (ECOPETROL 1998).

Here there were proposed four prospective areas, which include 5 structures. In addition, 7 leads were defined, they have a deficient seismic coverage and an uncertain knowledge about its dimensions and extension (Table 8).

Tabla 8. Previous Prospective Areas of the Ranchería Sub-Basin. Taken from Potential Oil-bearing Cesar-Ranchería Basin. ECOPETROL 1998.

Prospective area	Type of Trap	Structure	Exploratory Goals	Seismic Lines
Upar	Stratigraphic	Upar	Calcareo Set. Fm. La Luna Cogollo Gr.	CV-79-004 CV-79-01-B
Fonce	Stratigraphic	Fonce	Calcareo set.	CV-89-2220 CR-79-02-6
El carmen	Structural	El Carmen-1 Lead El Carmen-1 Lead El Carmen-2	La Luna Fm. Cogollo Gr	CV-88-1100 CR-79-02-3 CV-88-1670
Esmeralda	Structural	Esmeralda-1 Esmeralda-2	La Luna Fm. Cogollo Gr	CV-88-1100 CV-88-1260
Lead 3	Structural	La Vija	La Luna Fm. Gr. Cogollo	CV-89-1885 CV-89-1100
Lead 4	Structural	Barrancas	Fm. La Luna Cogollo Gr. CV-89-2280	
Lead 5	Stratigraphic		Calcareo.Set	CV-88-1670 CR-79-03
Lead 6	Stratigraphic		Calcareo.Set	CR-79-008 CV-88-1260
Lead Villanueva Subthrust	Structural	Villanueva Subthrust	La Luna Fm. Cogollo Gr.	CP-88-1400 CP-88-1140 CP-88-1200

Boreholes Data

An inventory was undertaken with the data corresponding to basic data of borehole such as:

- Top formations
- Geochemical analysis
- Biostratigraphic analysis
- Description of hearts of samples
- Geological Prognosis
- Log Data
- Coordinates

These data can be consulted on www.epis.com.co.

On Figure 9 the location of the boreholes in the studied region is shown.

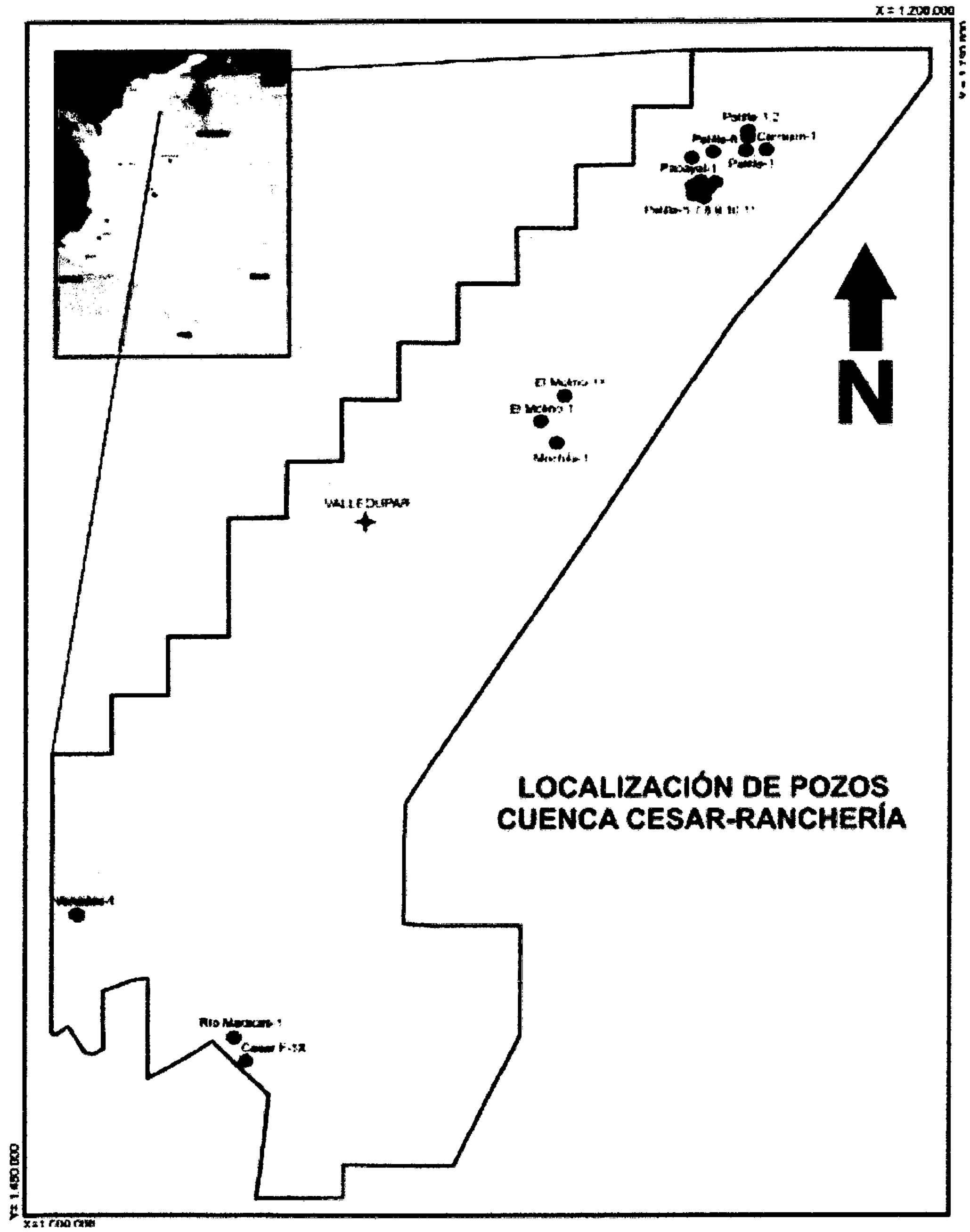


Figure 9. Location of Cesar – Ranchería Basin wells.

Geochemical Data

The results of the geochemical analysis are summarized in Tables 10 and 11.

Tabla 10. Average values of %TOC, TMAX and HI in the Perija´s Ridge.

Formación	*Roca*	*% TOC*	*TMAX*	*HI*
Los Cuervos	Lodolita carbonosa, arcillolita	14,47	436	132
	Carbón	50		
La Luna	Caliza	1,13	534	7
Tocuy y Maracas	Caliza	0,47	573	19
Tocuy y Animas	Caliza	0,61	509	9
Animas	Caliza	1,47	530	13
Lagunitas	Caliza	0,41	521	16
Rió Negro	Arenita, arcosa	0,78	543	9
La Quinta	Toba	0,73	513	8

Table 11. Average Data of %Ro in rocks outcropping in the Perija´s Ridge.

Formación	*%Ro*
Los Cuervos	0,53
La Luna	1,13
Tocuy y Maracas	0,95
Tocuy y Animas	0,82
Animas	1,16
Lagunitas	1,14
Rio Negro	1,14
La Quinta	1,41

Table 12 presents a summary of the geochemical evaluation, generating rocks, characteristics, and type of crude that they can generate or have already generated.

Table 12. Geochemical synthesis based on Tables 10 and 11.

EDAD	*FORMACIÓN*	*MATERIA ORGÁNICA*	*POTENCIAL DE GENERACIÓN*	*TIPO DE MATERIA ORGÁNICA*	*MADUREZ*	*ROCA FUENTE EN EL AREA*	*TIPO DE HIDROCARBURO*
Terciario	Los Cuervos	Muy Bueno-Excelente	Actual	III, IV y II	Inmadura-Inicio ventana	Potencial	Gas/Crudo
Cretácico	La Luna	Bueno	Agotado	II	Sobremadura	Consumida	Crudo/Gas
	Tocuy y Maraca	Bajo	No	II-III	Madura-Sobremadura	No	N.A
	Anima	Bueno	Agotado	II	Sobremadura	Consumida	Crudo/Gas
	Lagunitas	Bajo	No	II-III	Sobremadura	No	N.A
	Rio Negro	Bajo	No	III	Sobremadura	No	N.A
Jurásico	La Quinta	Bajo	No	III	Sobremadura	No	N.A

Surface Geochemistry

The data suggest the existence of anomaly zones, which are related with outcrops of Cretacic rocks (generating of hydrocarbons) (Figure 10).

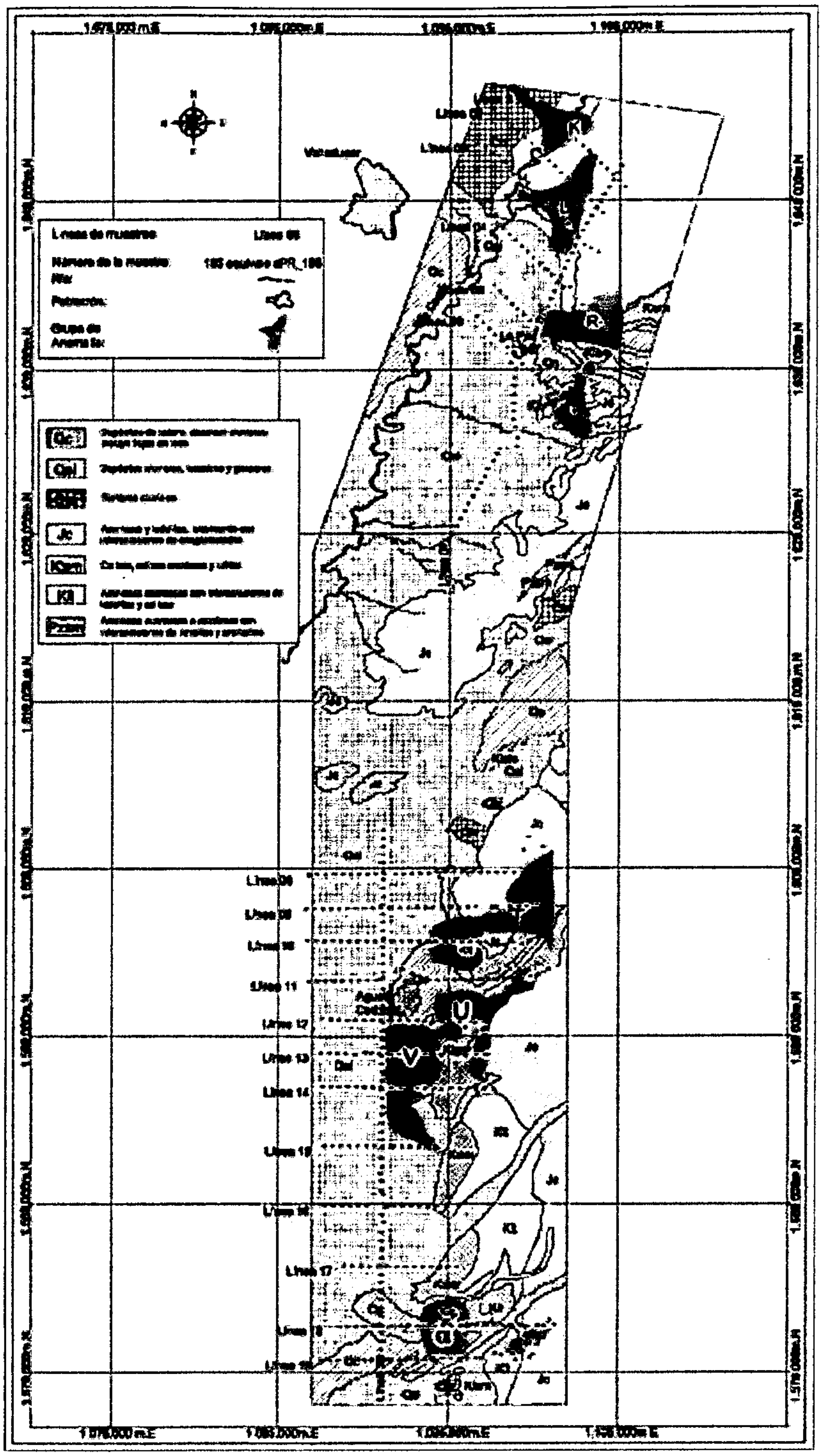


Figure 10. Map of the areas of the interest above the geological map. The relation between the anomalies of hydrocarbon and the outcrops of cretacic rocks can be seen.

Geochemical data of the boreholes

In Tables 13 and 14 the geochemical data available in boreholes are summarized:

Table 13. %Ro, %TOC, Tmax for the Cesar Sub-Basin.

SUBCUENCA CESAR					
Pozo	**Formación**	**%Ro**	**TOC**	**Tmax**	**Madurez**
Cerrejon-1	Molino	0,4-0,55			Inmadura
	La Luna	0,4-0,55			Inmadura
	Gr. Cogollo	0,55-0,68			Ligeramente inmadura (inicio ventana de generación de aceite)
Papayal-1	Molino	0,45-0,51			Inmadura
	La Luna	0,45-0,51			Inmadura
	Gr. Cogollo	0,51-0,58			Inmadura
Molino-1X	Barco-Cuervos		0,3	430	Inmadura diagénesis
	Molino		0,5	442	Inmadura diagénesis
	La Luna		0,18	431	Madura catagénesis

Table 14. %Ro, %TOC, Tmax for the Ranchería Sub-Basin.

SUBCUENCA RANCHERIA					
Pozo	**Formación**	**%Ro**	**TOC**	**Tmax**	**Madurez**
El Paso-3	Barco-Cuervos	0,45	20	420	Inmadura diagénesis
	Molino	0,38	1,61	424	Inmadura diagénesis
		0,61			Madura catagénesis
	La Luna	0,9	0,97	433	Madura catagénesis
Cesar F-1X	Barco-Cuervos		1,5	423	Inmadura diagénesis
	Molino		0,8-2	413	Inmadura diagénesis
	La Luna		0,9-5	471	Madura catagénesis

The project was carried out by ECOPETROL in 1990 in order to determine the quality of hydrocarbons presented in the Cesar and Ranchería sub-basins. Analysis of total carbon (TC) and total organic carbon (TOC) were realized. The results are summarized in Table 15.

Table 15. Concentrations of total carbon (TC) and total organic carbon (TOC) executed with the samples from wells. Modified of ECOPETROL 1990.

<table>
<tr><th>CUENCA</th><th>POZO</th><th colspan="2">FORMACIÓN</th><th>CONCENTRACIÓN TC</th><th>CONCENTRACIÓN TOC</th></tr>
<tr><td rowspan="7">RANCHERÍA</td><td rowspan="7">MOLINO-1X</td><td colspan="2">Conjunto calcáreo de la Guajira</td><td>Regular</td><td>Pobres</td></tr>
<tr><td colspan="2">Fm. Cerrejón</td><td>Regular a buena</td><td>Buenas</td></tr>
<tr><td colspan="2">Fm. Molino</td><td>Pobre</td><td>Regulares a buenas</td></tr>
<tr><td colspan="2">Fm. La Luna</td><td>Buena a excelente</td><td>Buenas</td></tr>
<tr><td rowspan="3">Grupo Cogollo</td><td>Superior</td><td>Buena</td><td>Buenas a muy buenas</td></tr>
<tr><td>Media</td><td>Buena</td><td>Regulares</td></tr>
<tr><td>Baja</td><td>Buena</td><td>Pobres</td></tr>
<tr><td rowspan="5">CESAR</td><td rowspan="3">CESAR F-1X</td><td colspan="2">Fm. Molino</td><td>Pobre</td><td>Pobre a buena</td></tr>
<tr><td colspan="2">Fm. La Luna</td><td>Buena a excelente</td><td>Buena a excelente</td></tr>
<tr><td colspan="2">Grupo Cogollo</td><td>Regular a buena</td><td>Regular a muy buena</td></tr>
<tr><td rowspan="2">PASO-3</td><td colspan="2">Fm. Molino</td><td>Pobre</td><td>Pobre (al tope), excelentes (parte media y base de la formación)</td></tr>
<tr><td colspan="2">Fm. La Luna</td><td>Pobre</td><td>Buena</td></tr>
</table>

Seismic Interpretation

The available seismic data was obtained on the GeoGraphix platform of Landmark. The interpretation of the seismic data was carried out in two independent projects; one for the Cesar Sub-Basin and the other for the Ranchería Sub-Basin. The seismic programs used in each one of the sub-basins are summarized in Tables 16 and 17.

Table 16. Parameters of the seismic programs available in the Cesar Sub-Basin.

Progr. Sismico	Regis. Para	Regis. Por	Long. (Km)	Calidad	N° Lineas Sismicas	Resol. Vertical	Resol. Horizon.
Valle del Cesar CV-79	Phillips Petroleum	GSI	1904	Regular	49	Moderada	Moderada
Mompos 81	Gulf Oil. Co	GSI	285	Buena	21	Moderada	Pobre
Guajira Cesar CR-88	Ecopetrol	Geosource	292	Buena	14	Moderada	Moderada
ANH 2005	ANH	UT KPITAL Geofisica	182	Buena	6	Buena	Buena
TOTAL			2663		90		

Tabla 17. Parameters of the seismic programs available in the Ranchería Sub-Basin.

Prog. Sísmico	Regis. Para	Regis. Por	Longitud (Km.)	Calidad	N° de Líneas Sísmicas	Resol. Vertical	Resol. Horizont
Ranchería CR-79	Ecopetrol	Western	492	Moderada	10	Moderada	Pobre
Guajira Cesar VNN CV-88	Ecopetrol	Geosource	156	Moderada	12	Moderada	Moderada
Sierra Perija CP-88	Ecopetrol	GSI	98	Pobre	6	Pobre	Pobre
Guajira Cesar CV-89 (Perija)	Ecopetrol	Western	270	Buena	11	Moderada	Moderada
Sorpresa 2D	Ecopetrol	Western	240	Buena	10	Moderada	Buena
Guajira Cesar VNS - 88	Ecopetrol	GSI - Digicon	87	Moderada	8	Moderada	Moderada
TOTAL			1343		57		

Seismic lines used and interpreted in each sub-basin

In the open area of the Cesar Sub-Basin, there are in total 49 lines of 5 different seismic programs. These 49 lines were reinterpreted and allowed the generation of structural maps in time and in depth lengthwise along the whole sub-basin.

Equally, there were reinterpreted the total of the 39 existing seismic lines in the open area of the Ranchería Sub-Basin, distributed in six (6) different seismic programs.

Cartographed horizons

The integration of the borehole´s data and the seismic interpretation allowed the definition of 4 seismic horizons of easy recognition and an evident continuity in tne area (Figures 11 and 12). From base to the top:

- Top of the Barco Cuervos Formation.
- Top of the La Luna Formation.
- Top of the La Quinta Formation.
- Top of the Basement.

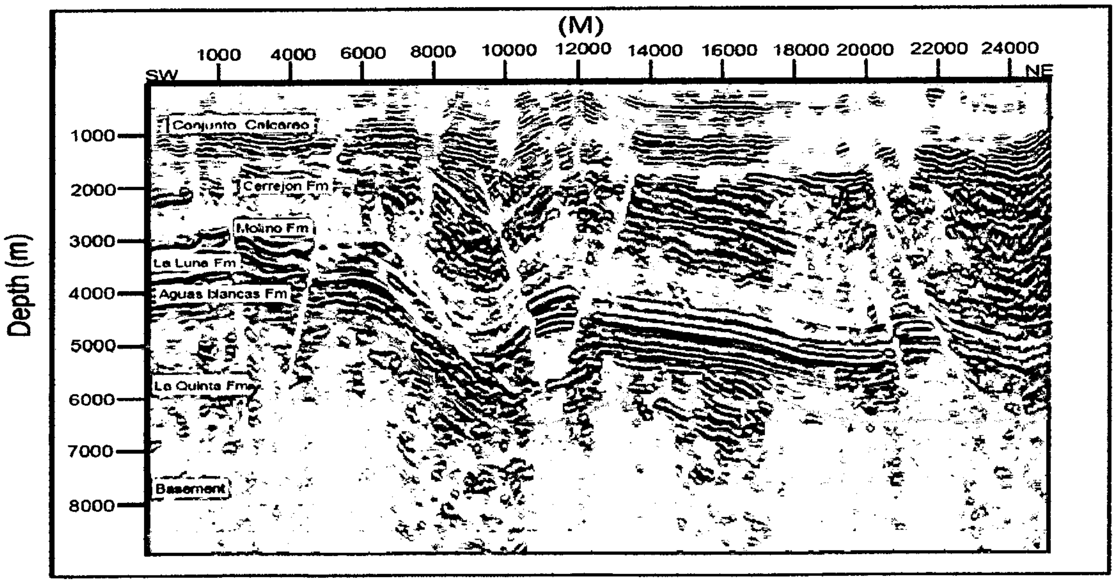


Figure 11. Seismic Horizons. Ranchería Sub-Basin.

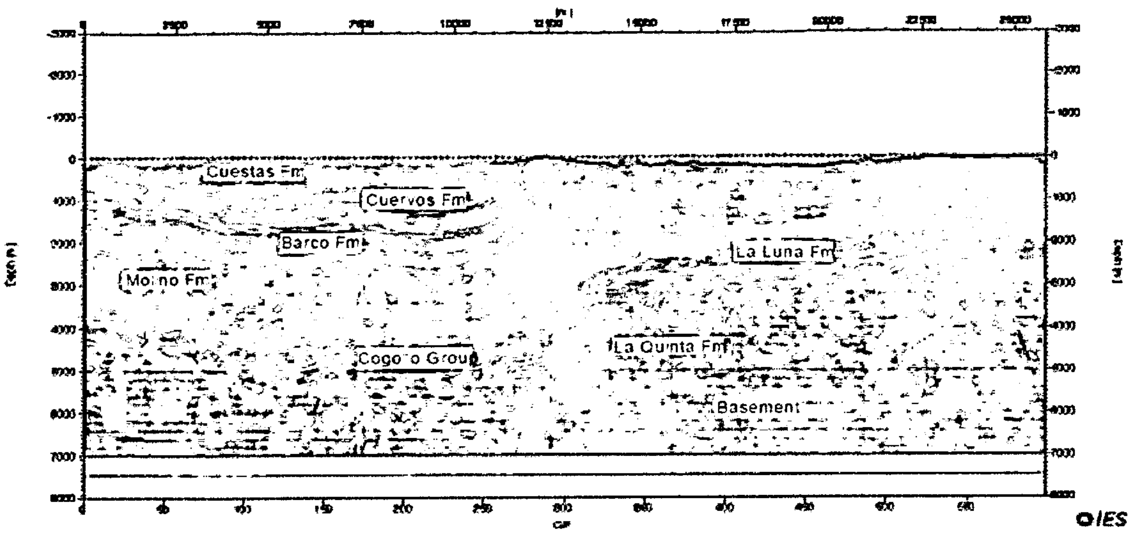


Figure 12. Seismic Horizons. Cesar Sub-Basin.

Structural maps. Top of the Basement

From north to south the presence of the Ranchería Thrust is observed, which is continuous along the whole Ranchería Sub-Basin. This north extreme presents a flattened surface and, as the movement advances towards the southeast, an abrupt descent culminated in the limit of both sub-basins. One elevation a little more pronounced, which corresponds to the structure of greater dimension in the map (Figure 13) is observed towards the west of the Ranchería Sub-Basin.

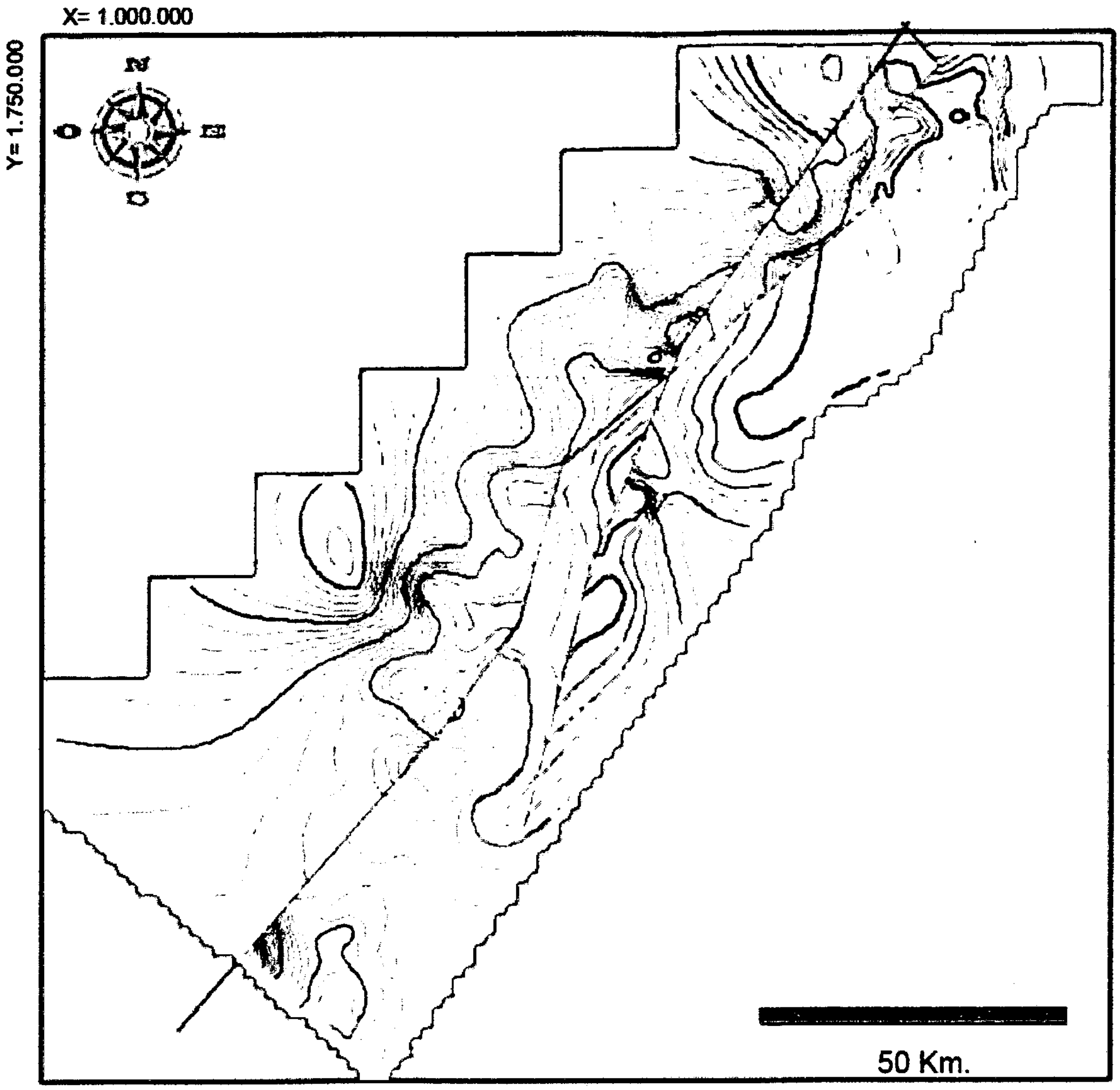


Figure 13. Structural map in time of the Top of the Basement. Ranchería Sub-Basin.

In the Cesar Sub-Basin, towards the border with the Ranchería Sub-Basin, two structural highs meet at the both sides of this Cesar-Ranchería 1 thrust. Advancing towards the south, a more regular surface with some slight rises is observed, and towards the southwest extreme a significant low structural feature can be identified (Figure 14).

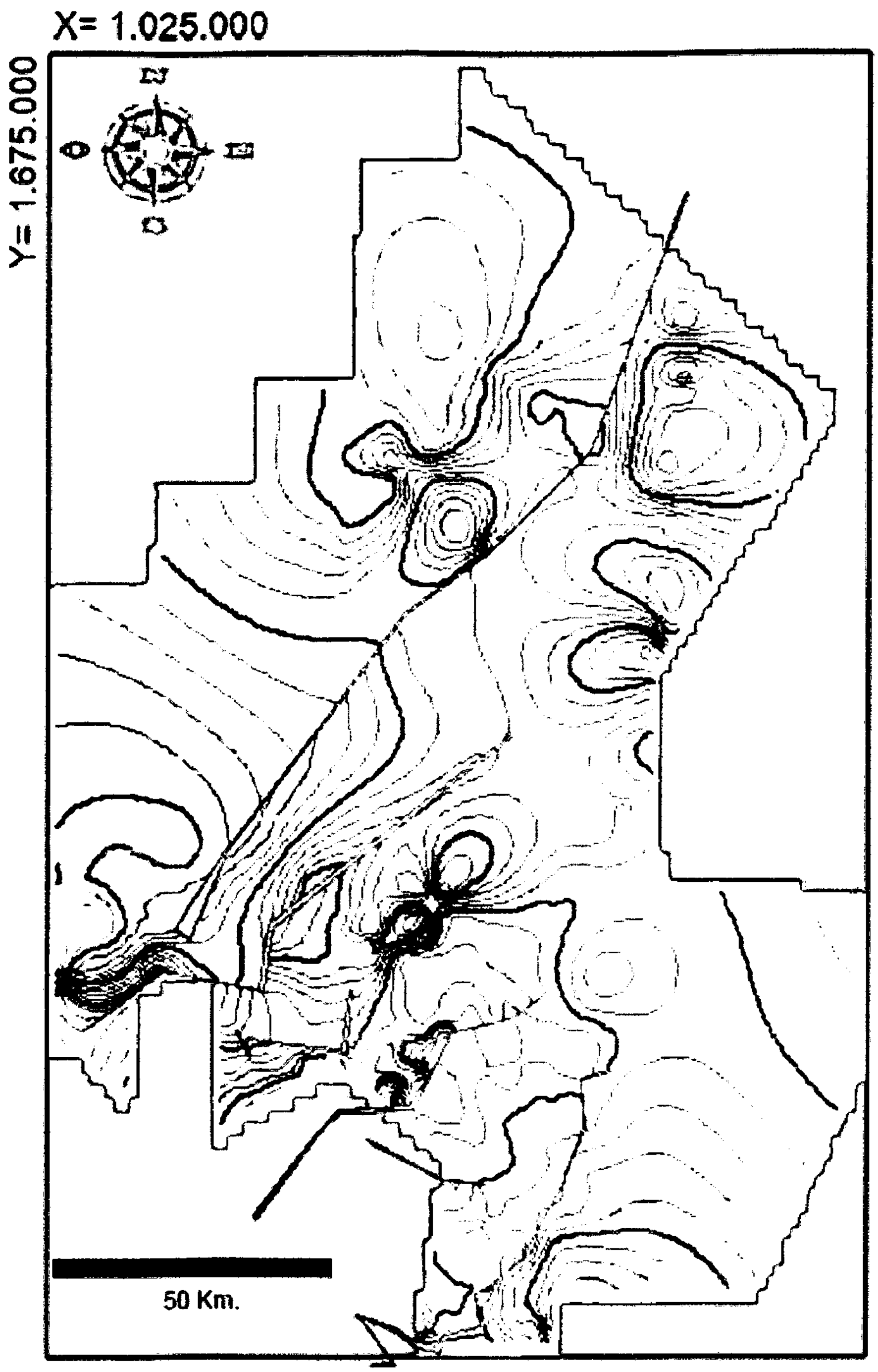


Figure 14. Structural map in time of the Top of the Basement. Cesar Sub-Basin.

Prospects

Through the integral evaluation of the geological, geophysical and geochemical data, it was possible to define areas with potential for the accumulation of conventional and non-conventional hydrocarbons in both sub-basins. In that way maps of leads for every one of the studied sub-basins were generated (Figures 15 – 18). See detailes in the Report of the Project.

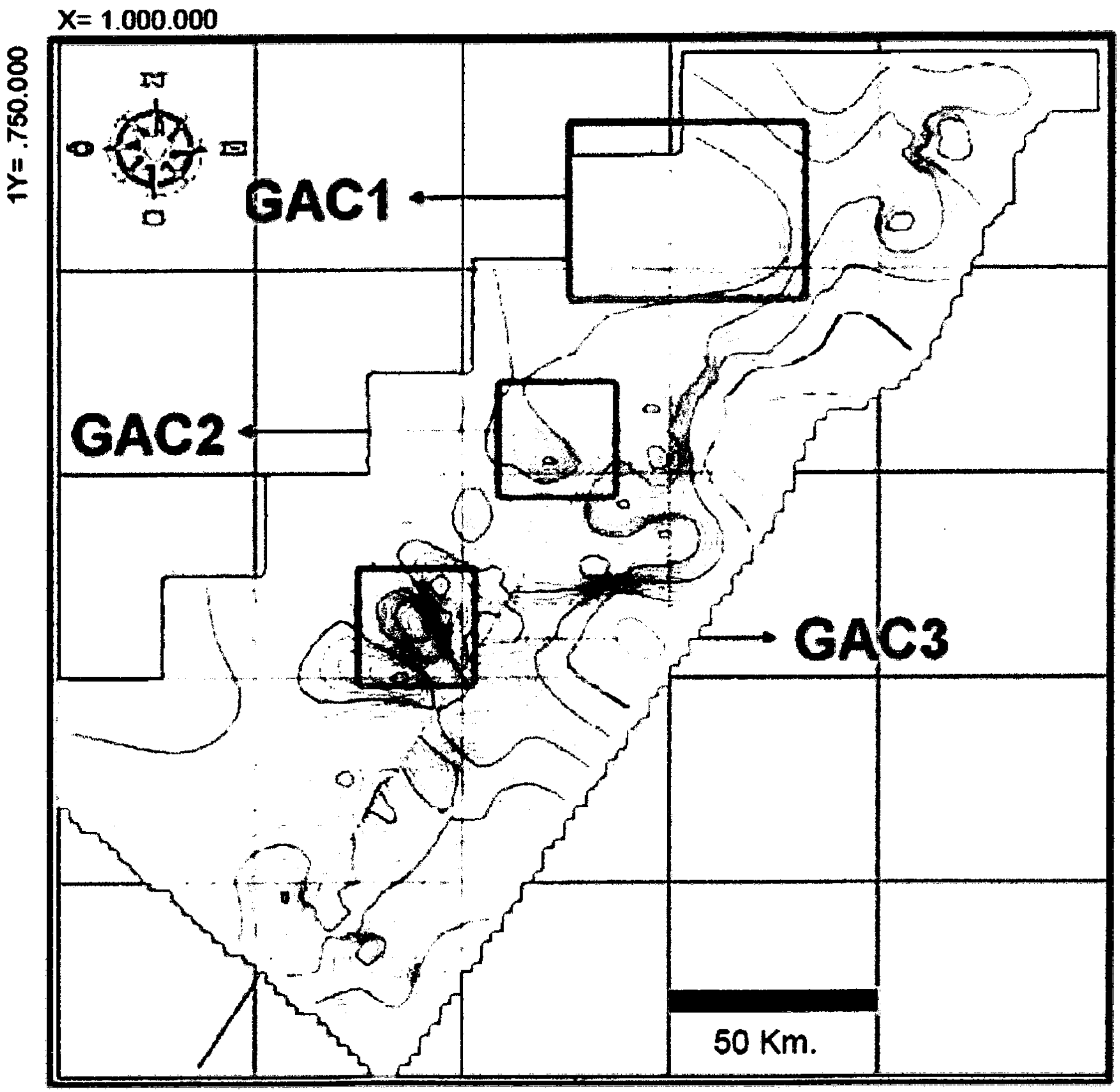


Figure 15. Prospective areas for methane associated with carbon. Ranchería Sub-Basin.

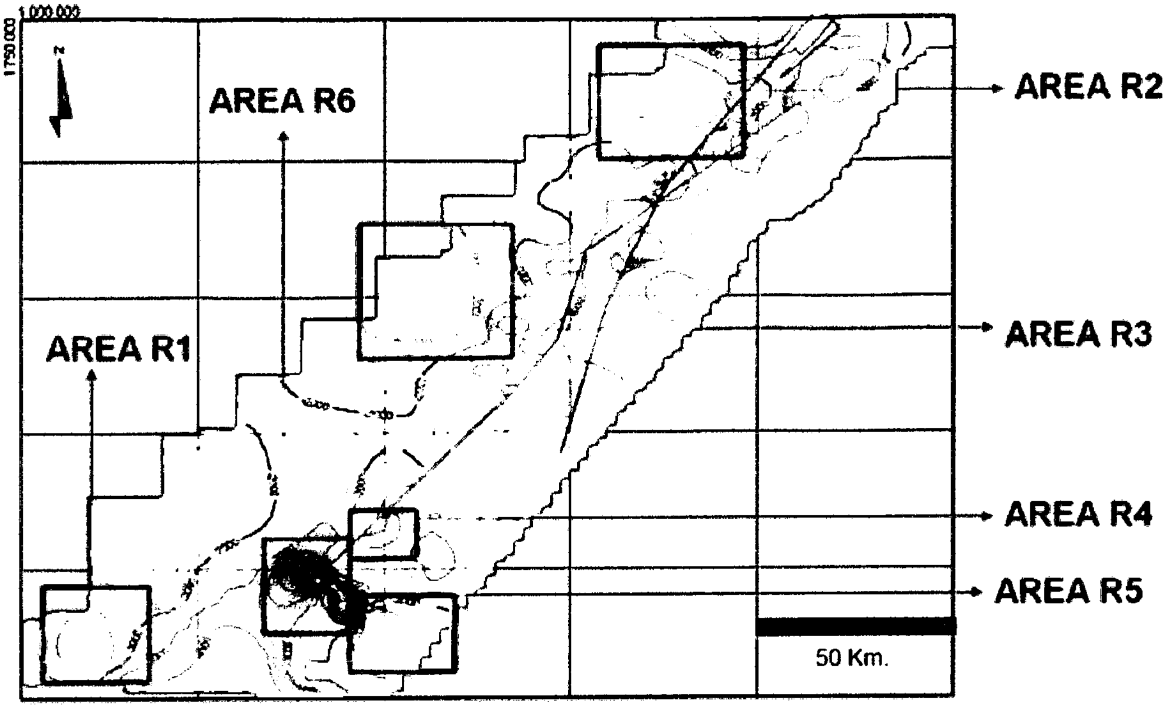


Figure 16. Prospective areas for crude. Ranchería Sub-Basin.

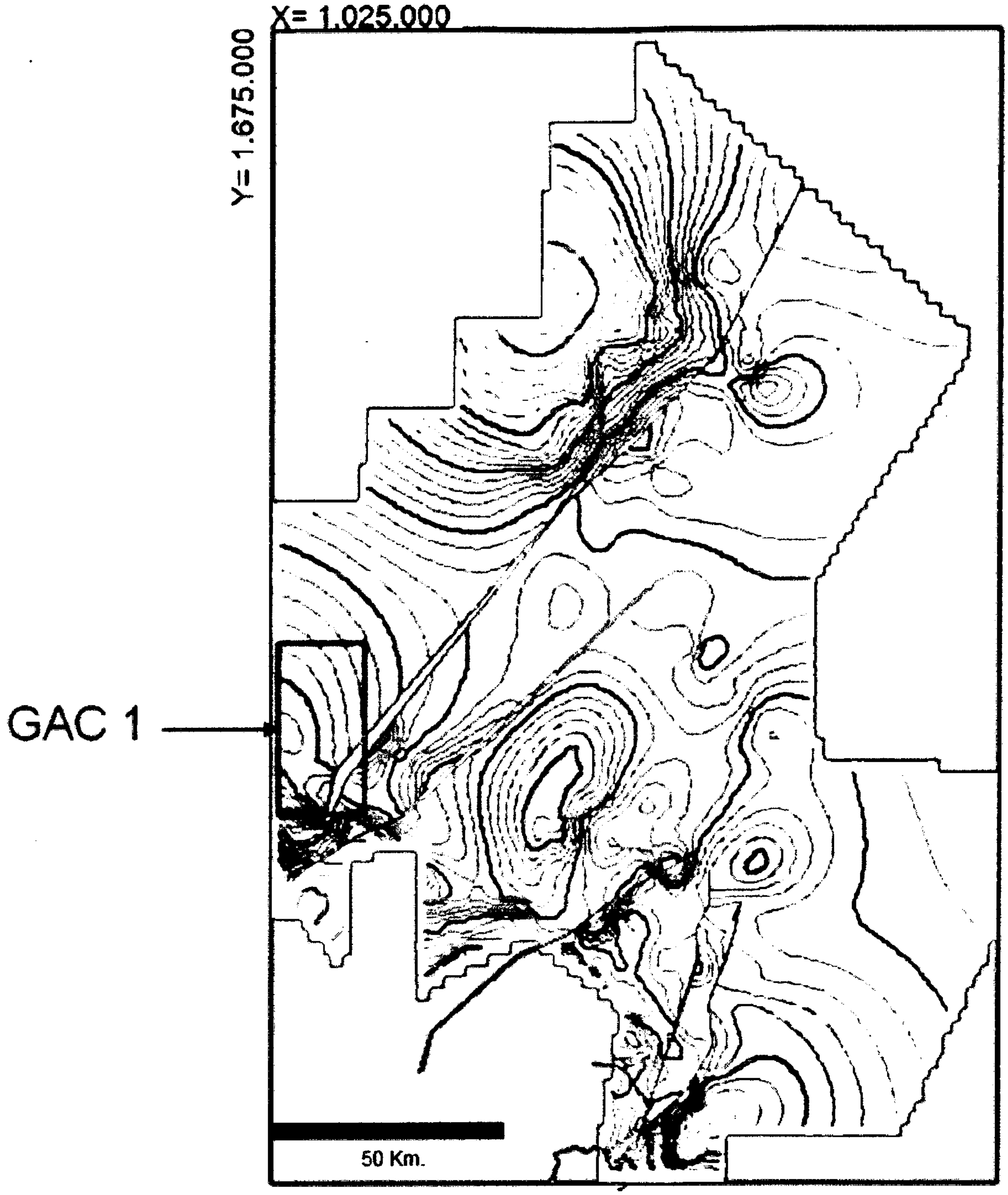


Figure 17. Prospective areas for methane associated with carbon. Cesar Sub-Basin.

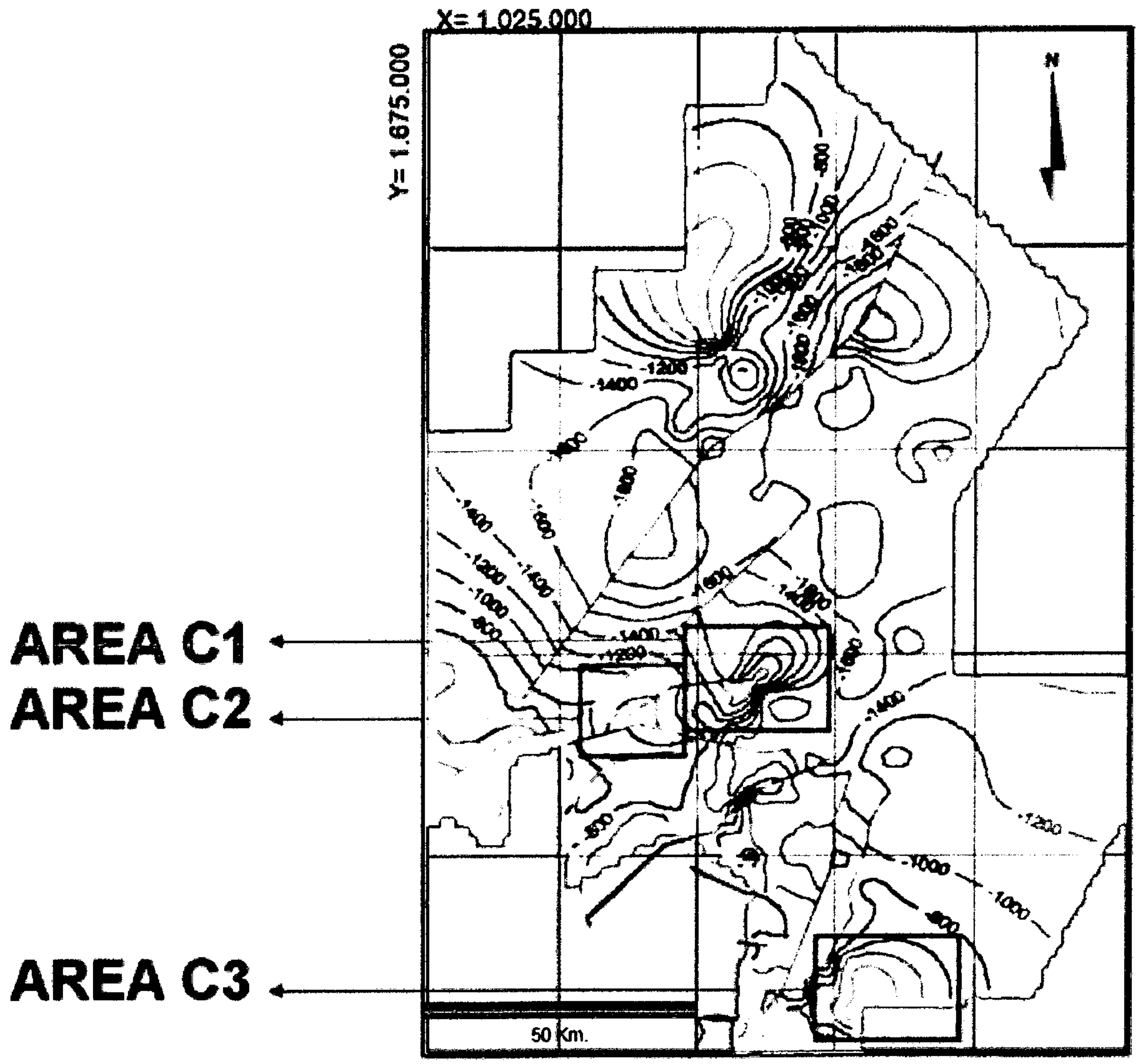


Figure 18. Prospective areas for crude. Cesar Sub-Basin.

Geochemical modeling

The results of the 2D modeling are presented on the Figures 19 and 20, which illustrate the routes of migration and accumulation of hydrocarbons. These results were derivated from the seismic profiles converted in depth. This data along with the data of content of organic material generated kinetically, paleotemperature, and pressure allowed delineating different zones of thermal maturity, as well as the routes of migration of hydrocarbons.

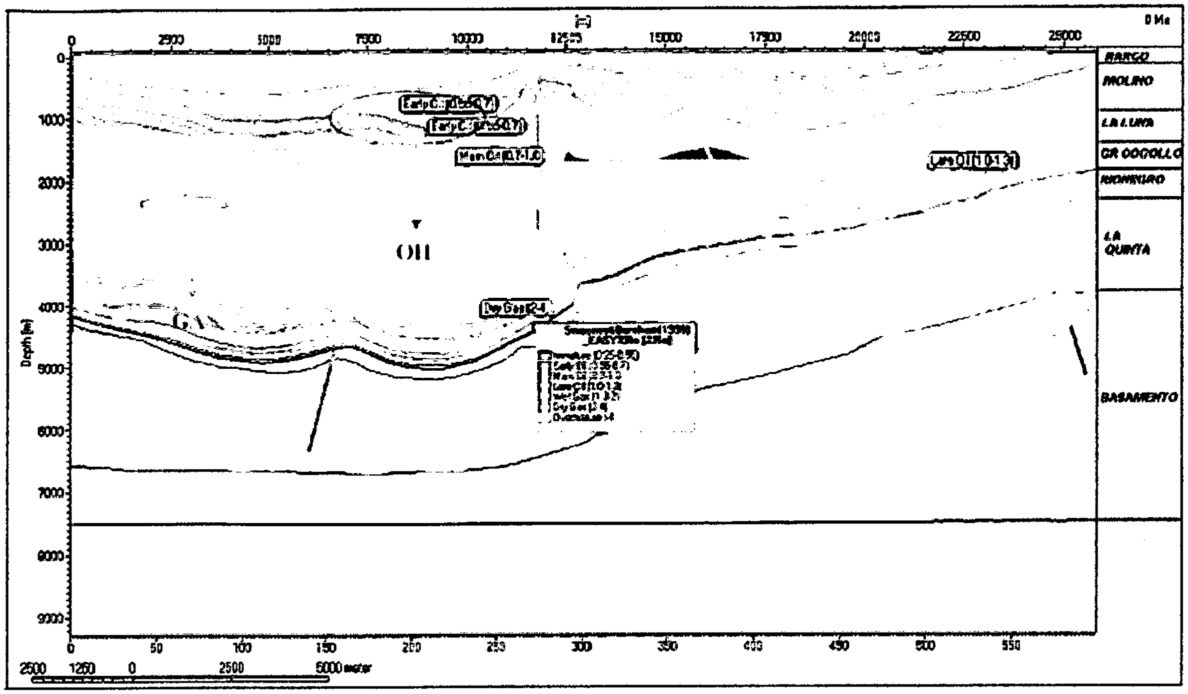


Figure 19. Geochemical 2D modeling for the line CR-88-1200 (Cesar Sub-Basin).

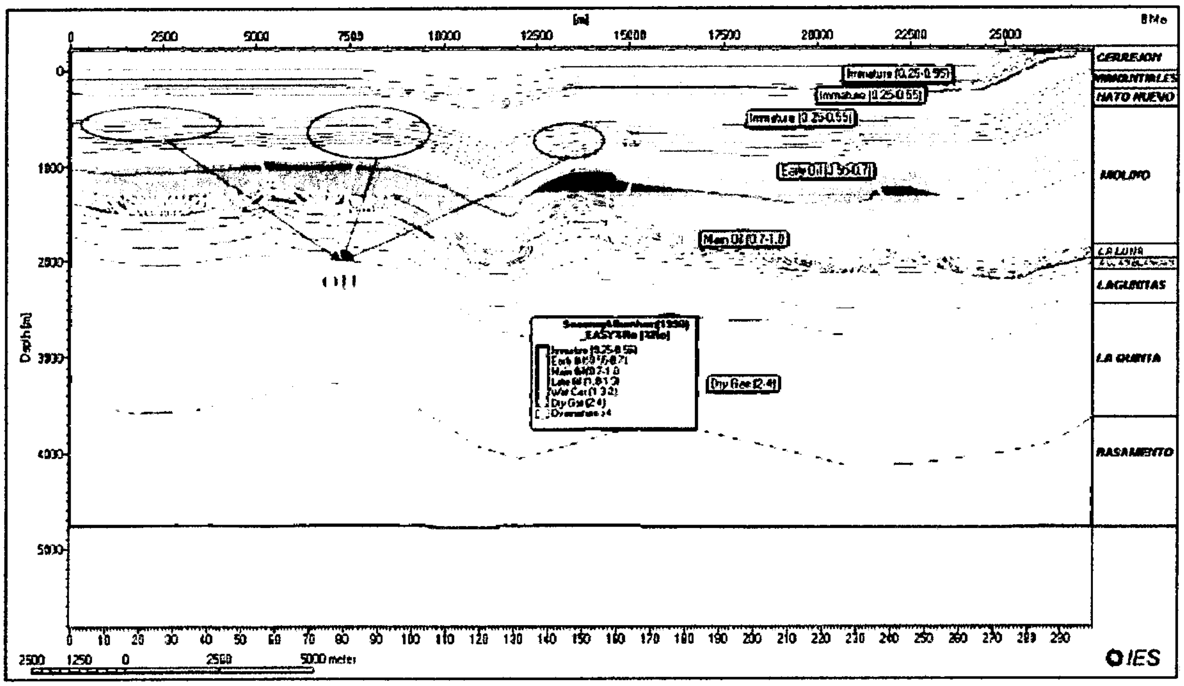


Figure 20. Geochemical 2D modeling for the line CR-89-1100 (Ranchería Sub-Basin).

CONCLUSIONS

- The gravimetrical data allows to guide the oil exploration to the depocenters of the Base of Cretaceous, where it is possible to find thermally mature rocks and hydrocarbon traps.
- The gravimetrical data of the Cesar-Ranchería Basin indicates the presence of three small depocenters in the Ranchería Sub-Basin and two in the Cesar Sub-Basin, where the depocenters located to the south have bigger dimensions. Likewise, the gravimetry shows that the depocenters of the Cesar and Ranchería sub-basins are separated by Valledupar paleohigh.
- Structurally, the Cesar-Ranchería Basin is affected by structural styles. The first style is the compressive blocks associated with E-W stresses and the second style is shear faults or right transcurrency.
- In the Cretaceous-Cretaceous system in the Cesar-Ranchería Basin, the original rocks are formed by the Cretacious sequence, including the Cogollo Group, La Luna Formation, and Molino Formation, of the ages from Aptianic to Maestrichtianic.
- The levels that present high concentration of organic materials are: inferior member of Lagunitas Formation, Las Ánimas Member of the Aguas Blancas Formation, inferior and midst of La Luna Formation and the shales of the superior Member of the Molino Formation. The original rocks consist in limestones and shales of marine platform.
- The reservoir rocks of this oil-bearing system are: the sandstones basal of Río Negro Formation, the fractured limestones from Lagunitas Formation, the sandstones of Tocuy Member, Aguas Blancas Formation, the limestones and the fractured cherts of La Luna Formation, and the sandstones of Socuy Member, Molino Formation.

- The regional rock seal of this system are the shales of Molino Formation and the intercalations of shales, which occur in La Luna Formation and Cogollo Group.
- The geochemical modeling indicates that this system is in the oil and/or gas window, depending on the deposit´s depth.
- In the Tertiary-Tertiary system of the Cesar-Ranchería Basin, the original rocks are composed of the coals and Carbonaceous shales of Cuervos Formation, in the Cesar Sub-Basin, and the coals of Cerrejon Formation, in Ranchería Sub-Basin. These two formations form the principal original rock for gas.
- The reservoir rocks of this oil-bearing system are principally composed of coal blankets of Cuervo and Cerrejon formations, deposits that are known as not conventional, of gas associated with coal (GAC).
- The seal rocks of this oil-bearing system are composed essentially of the shales of Barco and Cerrejon formations.
- In the Tertiary-Tertiary system of the Cesar-Ranchería Basin the principal gas deposit is formed by non-conventional deposits of gas associated with coal.
- Finally, this study allows identifying hydrocarbon resources, which were calculated in Cesar Sub-Basin for three possible scenarios that give the following numbers: 1 BBblse for the low scenario, 2.9 BBblse for the medium scenario and 6 BBblse for the high scenario.
- In the Ranchería Sub-Basin, the hydrocarbon resources are the following: 1 BBblse for the low scenario, 2.3 BBblse for the medium scenario and 4.7 BBblse for the high scenario.
- It should be highlighted that Cesar-Ranchería Basin, presents the same stratigraphic sequence as Maracaibo Basin, which is one of the most prolific hydrocarbon basins of the world. Besides, these two basins had been united as one since the Jurassic until the medium Eocene, when they were separated by the Perija´s Ridge Formation.

REFERENCES CITED IN THE ORIGINAL WORK

Geological Field-Trips Colombia, 1980-1989. Colombian Society of Petroleum Geologists and Geophysicists.

Project Cesar Ranchería, final report. Executive report. ICP. ECOPETROL.1990.

Project Cesar Ranchería. ECOPETROL. 1998.

3. CHOCÓ BASIN

This basin has been interpreted as the product of extension in a forearc setting. The north-northwest limit of the basin is the geographic boundary with Panamá; to the northwest the basin sediments lap on the basaltic complex of the Serranía de Baudó; the southwest limit is the present Pacific coastal line; the east limit is the quartzdioritic Mandé batholith and the Cretaceous rocks of the Western Cordillera. The Garrapatas Fault Zone, a NNE trending shear zone, marks the south limit of the basin (Figure 1).

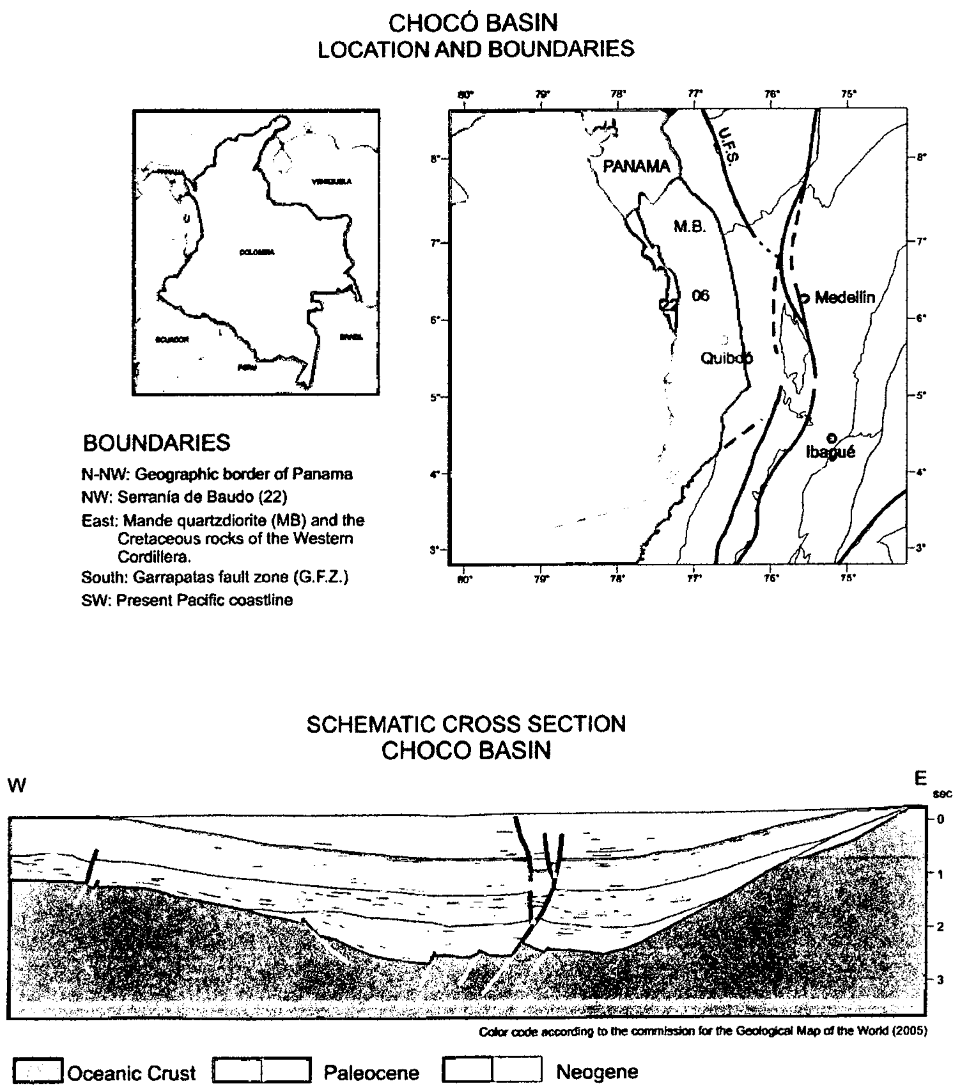


Figure 1. Chocó Basin.

SURFACE GEOLOGY AND CRUDE AND ROCKS GEOCHEMISTRY OF THE SAN JUAN SUB-BASIN (CHOCÓ)[1]

Servigecol Ltda.

Calle 82 No. 11-24 Of. 508 - Tel.: 571- 618 02 82

Bogotá D.C., Colombia

2008

INTRODUCTION

The surface geology of a 2225 km^2 area is presented on a 1:25000 scale, the 2735 m stratigraphic column survey is presented on a 1:200 scale, as well as Gamma Ray acquisition, and systematic sampling of the outcropping formations. Biostratigraphic samples were gathered for futher petrophysic, petrographic and AFTA analyses, with the purpose of characterizing potentially hydrocarbon-generating units and organizing the field information focused on determining the prospectivity and hydrocarbon potentiality of the San Juan Sub-Basin in Chocó Department.

OBJECTIVES

To execute the stratigraphic surface cartography and topographical survey of the San Juan Sub-Basin, based on the collected field information, and its further analysis and interpretation, with the purpose of assessing the existing prospectivity factors and hydrocarbon potential. Next, we list the specific objectives:

- To carry out the geological cartography of a 2225 km^2 area.
- Description, interpretation and evaluation of the structural geology in the study area.
- To survey 2000 m of stratigraphic columns in outcropping units, which may have incidence on the hydrocarbon exploration.

---

[1] Geología de superficie y geoquímica de rocas y crudos de la Subcuenca del San Juan (Chocó). Informe Final. Diciembre, 2008.

- To gather at least four hundred samples of lithologic units with characteristics of source, reservoir, and seal rocks.
- To gather samples of existing hydrocarbon seeps in the study area.
- Geochemical characterization of the potentially-generating units and the hydrocarbon seeps.
- Crono-Stratigraphic dating of the lithological units.
- Integration and interpretation of the collected geological information.

LOCATION

The study area approximately comprises the sectors located between Buena Suerte Town (southern sector), and Capirito and Agua Sucia small villages (northern sector) in the San Juan Sub-Basin in Chocó Department (Figure 1).

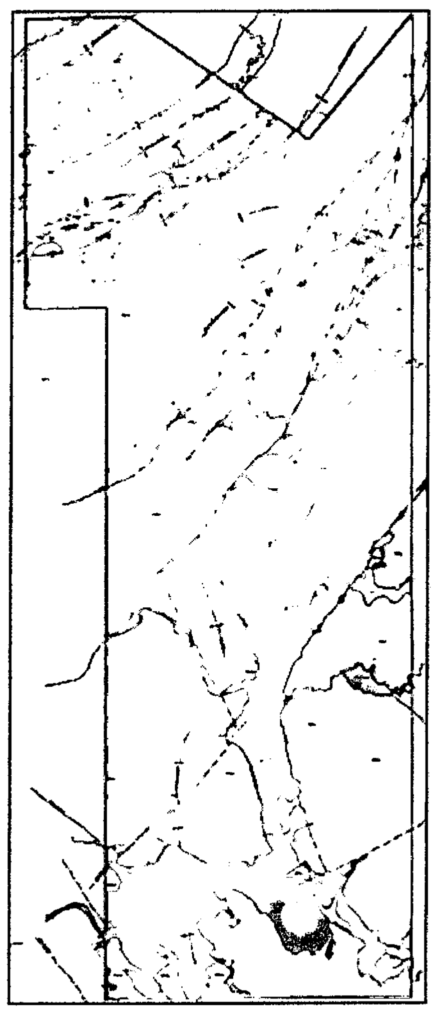


Figure 1. San Juan Sub-Basin.

METODOLOGY

Pre-activities – Field work

On this stage, all available technical information regarding the study area was reviewed.

Field Phase

11 geologic sections and 5 stratigraphic sections (Quebrada Agua Clara, Ladrilleros, Quebrada Malambo, Quebrada Grande and Río Siguirisua) were selected. At the same time, larger intervals were defined according to distinguishable stratigraphic sequences, as well as descriptions of the more general characteristics of the rocks such as thickness, composition, color, texture and structural data. Gamma-ray readings were realized by using an RS-125 spectrometer.

Office Phase

After the field work it was time to organize the acquired data, to digitize the columns, to generate maps, and to edit the photographs, as well as to describe macrocopically and re-label the samples of the Quebrada Agua Clara, Ladrilleros, Quebrada Malambo, Quebrada Grande, and Río Siguirisua River sectors. The final report, available in the Agencia Nacional de Hidrocarburos (ANH), includes the following:

- Final report.
- Photogeological map on a 1:50000 scale.
- Geologic map on a 1:50000 scale.
- Structural map on a 1:50000 scale.
- Structural retro-deformable sections on a 1:25000 scale.
- Map of Stations on a 1: 50000 scale.
- Stratigraphic Columns Graphs on a 1:200 scale.
- Stratigraphic Columns Polygonals Graphs on a 1:5000 scale.
- Digital photos.
- Compatible Access data bases.

Surface Geology

2717.58 m of stratigraphic column in five sections were surveyed, chosen according to INGEOMINAS base map. 1779.30 m of rock and 938.28 m covered sectors were described, and 332 samples were collected.

Regional Tectonic Framework

The study area is limited within the regional context by the so-called Mandé Magmatic Arc, which is part of the western flank of the Western Cordillera and the Baudó Mountain Chain, to the east and west respectively. This is a terrain constituted by an accretioned oceanic base to the NW of the Western Cordillera during the Miocene. It suggests that a thick sedimentary sequence of the Miocene found in the area was deposited in a formed previously basin or apparently simultaneously formed with the accretion processes, and deformed at least partly during the same process.

To the south of the study area, the denominated deformed zone of Istmina appears. This is the zone of NE-SE-oriented fault that is interpreted as the southern flank of the suture zone, formed as a result of the Chocó Block accretion.

Photogeologic Interpretation of San Juan Sub-Basin (Chocó)

Heliographic copies of the mosaics using INTERA radar images at a 1:50000 scale and aerial photos, panchromatic, with an average of 1:48000 scale were used with acceptable resolution and contrasts. Additionally, the available information was used as a reference on maps at 1:100000 scale published by INGEOMINAS in 2002, extended to scale 1:50000, as well as the digital land elevation model, at a 1:100000 scale. The results of the geologic photo-interpretation results at a 1:50000 scale were geo-referenced and vectorized in ArcGis, where two structural blocks are observable, divided in five sectors, with a direction different from their geologic components, separated by the San Juan River Fault. This photogeologic interpretation was integrated with the digitized topographic map, and shown on the Photogeologic Map. The area of photogeologic interpretation in the San Juan Rver Basin is represented by an irregular polygon extended 75 kilometers in a N-S direction and limited by 35 km in the E-W direction. The San Juan River flows from northeast to southwest on a wide alluvial plain with large meanders, which contrasts with more rectilinear sectors due to structural and lithological factors. The river initially flows 20° in the SW direction until the confluence of the Docordó River, then with a N-S direction by a passage of 35 km, up to the Munguidó's River mouth, where it flows almost in the E-W direction. This happens due to changes in the length and to the amplitude of its meanders. From this point the San Juan River shows a strong deflection towards the west, where the meander development is very tight and irregular. This behavior may imply possible structural and lithological controls, which were not very evident on the radar and on available aerial photographic images, but may suggest that they could match the possible Munguidó and Calima faults on the southern end of the analyzed area.

Structural Geology

The study area was divided in two main structural sectors: one central-north and another southern, which are separated by the San Juan Fault. The central-north sector is characterized by faults and folds whose axes are oriented mainly SW-NE and predominantly affect the Miocene rocks. The Istmina Formation and Condoto Formation correspond to lodolitic units that predominantly appear underlying and overlying the respective levels of thick conglomerates denominated Conglomerados de la Mojarra Formation. A NW oriented structural sequence, which is clearly different from the one observed in the central-north sector, is noticed preferential in the southern sector of the study area. In this sector, the geomorphological expression of the units is relatively poor, and the structure definition has been mainly achieved with the help of satellite images and aerial photos. The structural solution suggests high angle faults, probably with course components. This solution is compatible with the presence of folds on echelon structure, associated to relatively straight fault outlines observed further to the north and northeast but outside the study area, which were supported by the digital elevation model.

Considering the presence of observed folds on echelon structure (Figure 2) it is possible to notice a NW-oriented compression, almost perpendicular to the axis of the folds. These folds allow interpreting the possible presence of a fault of important course that limits the eastern flank of these folds and may be a previously-formed discontinuity zone.

Figure 2. Axes of folds on echelon structure to the north of the study area. They suggest a main NW-SE direction of compressive stress. Digital Elevation Land Model.

Stratigraphy

The mapped litho-stratigraphic units are, from oldest to newest, the following: the Istmina Formation (E3N1is), Conglomerados de la Mojarra Formation (N1cmj), Condoto Formation (N1cn), Mayorquín Formation (N2my), and Recent Deposits. The biostratigraphic zonation allowed to delimit these units, and to execute lithological correlations in such area where, due to the facies changes, it had formerly been very difficult to establish correlations using other methods. A chronological correlation of the units observed in the Atrato River Sector (dated by

METODOLOGY

This study was developed as follows:

1) Compilation, analysis, and assessment of existing information

2) Photogeological and remote sensing interpretation

3) Field verification

    Geological cartography

    Stratigraphic columns survey

    Seep sampling

4) Transects with structural emphasis

5) Stratigraphic columns survey and sampling

    Gamma Ray acquisition

    Rocks Sampling

        Sampling for biostratigraphic analysis

        Sampling for petrographic and petrophysic analysis

        Sampling for geochemical analysis

        Sampling for seep analysis

6) Analysis, editing and digitalizing of the different deliverable products

Cartographic Units

The stratigraphic units mapped in the area include ages that go from the Late Cretaceous (Santa Cecilia-La Equis Complex) to recent times (Quaternary Deposits: Qal and Qt).

Structural Geology

The study area is located north of the area called by Duque-Caro (1990) the Istmina Deformation Zone, an area of very high structural complexity. The regional structural trend in the study area is N50E, and it changes to an E-W trend near the Western Cordillera. Four important structures are prominent in the area: The San Juan Fault, the La Mojarra Syncline, the Ñápera Anticline, and the Iró Fault.

Structural Traverses

10 transects were carried out (San Juan River, Muchidó Creek, neighborhood of Santa Rita, Tadocito River, Chato River-La Larga Creek, Mongarrá River, Profundó

& Colorado Creeks, Condoto River, Apartadó-Tirado Creek) (as an example see Figure 2). As a general comment about access to the sites, it is important to mention that almost all sites are creeks and/or rivers, with occasional segments that cross the jungle at multiple interfluves. Therefore, it is necessary to travel in the company of natives who know the area, especially near the river basin zones.

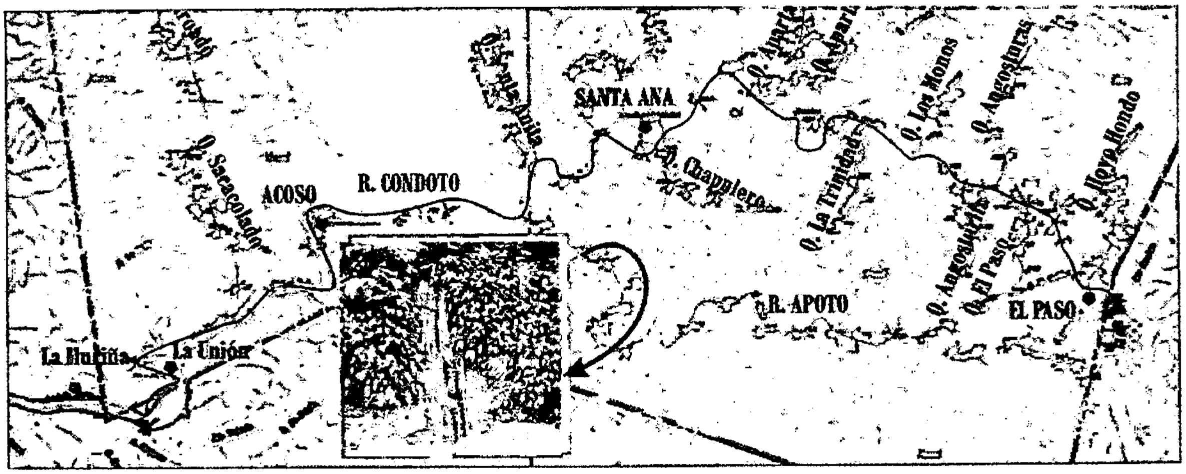


Figure 2. Condoto River Transect.

Kinematic Analysis

Faults with kinematic displacement indicators were analyzed using the Angelier, Alexandrowski (1985), and Marrett & Almendieger (1990) methods, in order to obtain the main stress axes trends. The data was processed using the StereoNett 2.46 version program, in order to obtain initial estimates of the main stress axes trends through the determination of the motion planes. Then the process was repeated using the FaultKinWin 1.1 for Windows program, which integrates the methodologies stated by the above-mentioned authors. The stereograms were projected on an equilateral grid in the lower hemisphere. These stereograms show the faults with their kinematic indicators, nodal plans, and main stress axes. All the stereograms were integrated on a structural map.

RESULTS

Tables 1 and 2 show the identified elements:

Table 1. Folds.

Element	Length	Course
La Cuelga Anticline	15 km	N40E (after N80E)
Colorado Anticline	7.2 km	N55E
Chirrinchá Anticline	7.5 km	N30E
Ñápera Anticline	16.5 km	N75E
El paso Anticlinal	3.5 km	N35E
La Sierra Syncline	10 km	N40E (after N80E)
La Mojarra Syncline	22 km	N60E
Zambullidero Syncline	6.5 km	N25E
La Trinidad Syncline	5.5 km	N50E

Table 2. Faults and Lineaments.

Fault	Characteristics	Length (km)	Course	Vergence
San Juan Fault	Inverse nature with a strong dextral transcurrent component	19	N50E	Tectonic dominant vergence northwestward
Chato Fault	Inverse nature with a dextral lateral displacement component	18	N60E	NW
La Mojarra Fault	Inverse	8	N45E	NW
Iró Fault	Inverse	27	N50E	NW
Tadocito Fault	Inverse nature with a strong dextral transcurrent component	9	N-E	N
Pacurundú lineament	Element parallel to the La Mojarra Syncline axis		N62E	---
El Convento lineament	Element parallel to the La Mojarra Syncline axis		N60E	---

Stratigraphy

During this field campaign, the following stratigraphic sections were measured: San Bernabé Creek, Santa Catalina Creek, Manantial Creek, La Cuelga Creek, La Larga Creek, Manungará Creek, San Juan River (Figure 3).

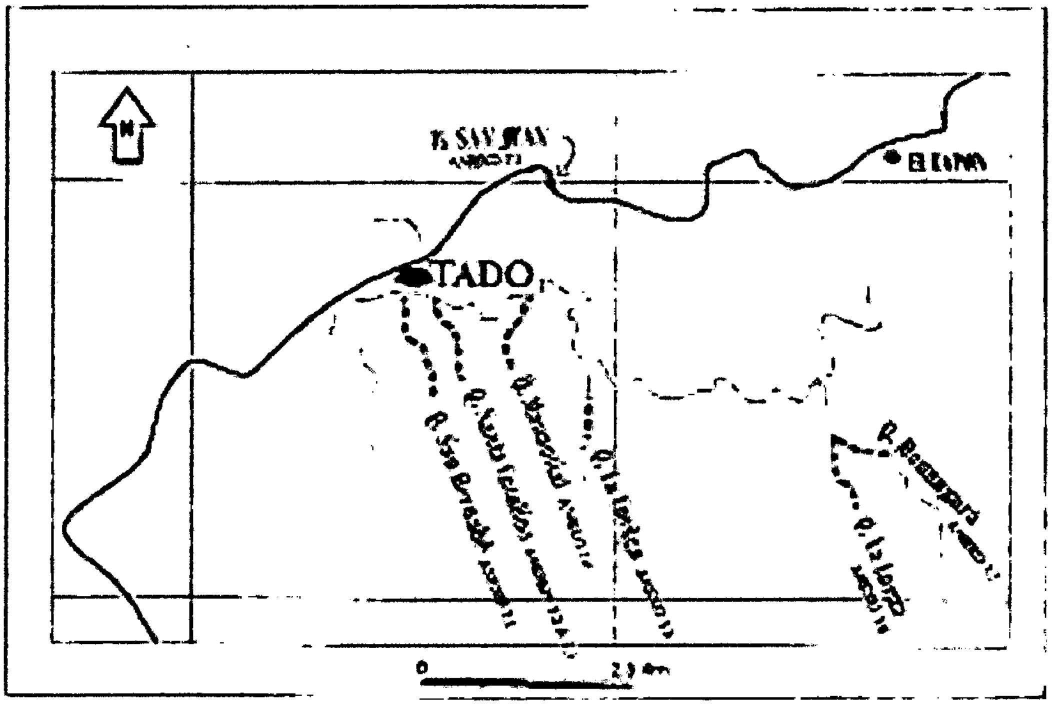


Figure 3. Location of the surveyed stratigraphic sections.

Microstratigraphy

A total of 25 surface samples from the Istmina-Tadó Area in the Chocó Department were studied. 8 samples resulted insufficient for diagnostic determination. The remaining 17 samples showed microfaunistic associations; this places them within the Middle Miocene to High Middle Miocene interval, and within the Late Paleocene to Middle Eocene interval.

Correlation

The dating of the samples from the Urodó-1 Well report a time frame that goes from the Early Miocene to the Middle Miocene, allowing a chronostratigraphical correlation of the interval with the Istmina (Early Miocene) and Conglomerados de la Mojarra formations (Early to Middle Miocene) belonging to the San Juan Group and outcropping in the study area. The range of lateral facies of these two units is said to have sandy silicoclastic to conglomeraic deposits in the southeastern part of the correlation area (work site with proximal deposits), gradually changing towards the northeast to finer silicoclastic deposits interbedded with occasional calcareous layers (distal deposits).

Petroleum Geology

Source Rock

The geological cartography identified claystone, shale, and limestone stratigraphic layers of the Iró Formation as main source rocks for hydrocarbon generation. The distribution and stratigraphic thickness of this rock is continuous throughout the study area, confirming a great volumetric generating potential for future prospecting.

Reservoir Rock

Usually, there are outcrops of associated material on the source rock on the above-mentioned sites, and they are distributed at regional levels throughout the study area. According to field observations, as primary reservoir we have the sandy layers of the Istmina Formation, as well as the limestones of the Iró Formation. As secondary reservoir we have the silicoclastic layers of the Conglomerados de la La Mojarra Formation.

Seal Rock

The Tertiary Succession of the Iró Formation and of the San Juan Group (outcropping in the study area) shows important claystone intervals with ample geographical distribution, which act as potential seal for the reservoir due to their characteristics, both for structural traps as for stratigraphic traps, considering the series of divergences that affected the sedimentary concentration in the study area.

Seeps

Four seeps were located in the study zone. Two of them are of liquid hydrocarbon and other two are of oil-wet rock. Three are located in the Iró Formation and one in the rocks of the Santa Cecilia-La Equis Complex (Iró River).

CONCLUSIONS

- The geological survey that was carried out established that in the study area there is an outcrop of a tecto-sedimentary sequence that records a range of events that go from the Upper Cretaceous (Santa Cecilia-La Equis Complex) to the Lower Miocene (Istmina Formation and Conglomerados de la La Mojarra Formation).

- Field evidence establishes the presence of two discordances in the stratigraphic sequence, which control the Sub-Basin sedimentation cycles as follows: The first one is of the Upper Eocene-Lower Miocene age, recorded between the Iró Formation and the Istmina Formation. The second one is of the Lower Miocene-Middle Miocene age, allowing contact of the Istmina and Conglomerados de la Mojarra formations.
- The geological conditions of the area show the existence of source rock (shales from the Iró Formation), reservoir rock (limestone and silicoclastic rock types from the Iró Formation) and Tertiary Layers of seal rock for possible hydrocarbon reservoirs within the area of interest. Added to the above, there is field evidence that proves the generation and migration of fresh oil through the Santa Rita Seep and the El Padre Creek.
- The structures in the study area have a predominantly N50E trend. Three regional structures are seen in this zone, namely: San Juan Fault, La Mojarra Syncline, and Ñápera Anticline.
- The area consists of a series of wedges with a northwestern trend, resulting in and deformation episodes occurred before the settlement of the Conglomerados de la Mojarra Formation, and a last transpressive dextral event evidenced by the different kinematic indicators measured throughout the San Juan and Todocito faults. The main stress components for the area are roughly N-S, resulting from the last compression and strike events that happened simultaneously in the area.

REFERENCES CITED IN THE ORIGINAL WORK

Aleksandrowski, P. (1985). Graphical determination of principal stress directions for slickenside lineation populations; an attempt to modify Arthaud's method. Journal of Structural Geology 7, pp. 73–82.

Duque-Caro, H. (1990). The Choco Block in the northwestern corner of South America: Structural, tectonostratigraphic, and paleogeographic implications. Journal of South American Earth Sciences, Vol 3, No 1, p. 71-84, Great Britain.

Marrett, R. and Allmendinger (1990). Kinematic analysis of fault-slip data. Journal of structural geology, Vol. 12, No 8, p. 973-986. Great Britain.

GEOCHEMICAL SURFACE SURVEY: CHOCÓ BASIN, SAN JUAN AREA[1]

HIDROGEOLOGÍA, GEOLOGÍA, AMBIENTAL LTDA – HGA LTDA.

2006

INTRODUCTION

The sampling of canned gas in free space is one way of analyzing volatile compounds linked to a sample without the use of extraction by solvents. The term "headspace" refers to the free space between the upper part of the liquid or solid content and the lid of a tin can. This technique is usually referred in the pharmaceutical ambit as headspace gas chromatography, and the objective is to analyze the vapor of the substance present in the space between the level of the liquid (or solid) and the lid of a tin can.

OBJECTIVE

Acquisition of 600 soil samples and processing by headspace gas chromatographic analysis with the purpose of detecting and quantifying existing light gases.

LOCATION

The sampling area is located in Chocó Department (Figure 1), and it is surrounded within the polygon with coordinates (origin Bogotá) that are presented on Table 1.

[1] Estudio geoquímico de superficie. Cuenca Cordillera Oriental, Área Soápaga y Cuenca Chocó, Área San Juan. HGA Ltda. Mayo, 2006.

Table 1. Coordinates of the polygon of the sampling area.

Vertex	North (m)	East (m)
P1	1078505	743297
P2	1036567	739763
P3	995336	715731
P4	1006881	675914
P5	1052824	694291
P6	1078505	715260

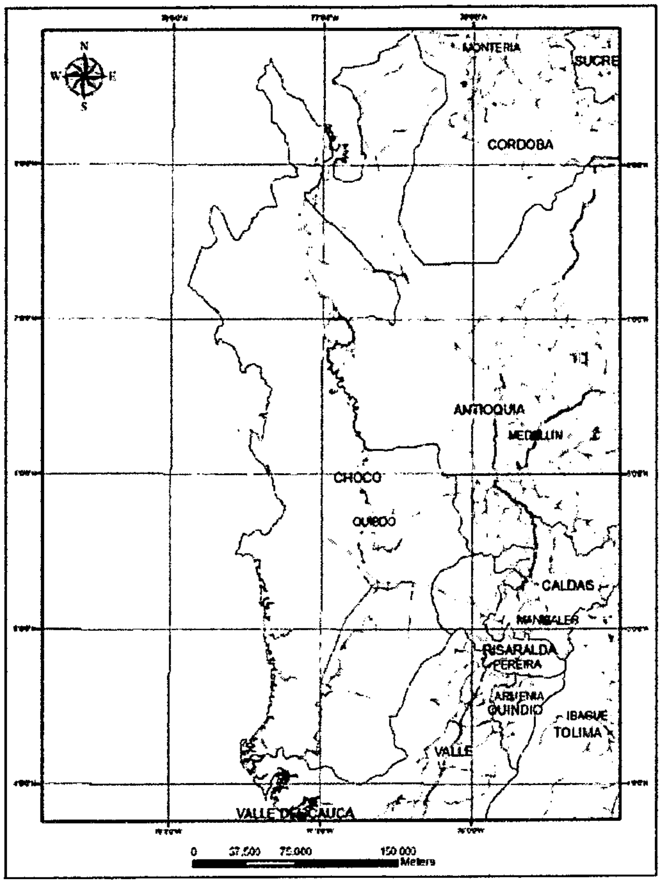


Figure 1. Location of the study area.

METHODOLOGY

The steps during the acquisition, processing and interpretation of geochemical data are presented as follows:

1) Sampling

- The first fase was a sampling grid based on previous geological studies, which define structural characteristics of possible exploratory interest. This grid includes 14 sampling lines: 10 of E-W direction, perpendicular to the main faults, and 4 of N-S direction. The distance between the sampling lines is approximately 2 km and between the sampling points, at each line, is 500 m.
- From this grid, having the location of the sampling points, sampling points were consecutively enumerated, naming the first point SJ-1, and the last sample SJ-600. Later on, the Bogotá origin coordinate of each point was read. A listing of coordinates was generated with which later on, each GPS was loated daily, according to the points assigned to each geologist for field sampling.
- Before starting the sampling, a stage of area recognition was carried out with the purpose of designing the sampling strategy according to the accesses. This was done in order to obtain the corresponding permits to have access to the properties involved in the sampling, to hire auxiliary personnel and vehicles and to choose the base sites.
- A manual auger was used for the drilling of holes, which have depth between 0.80 and 1.50 m and are approximately 15 cm in diameter. The end depth of the hole is determined by getting to the fresh soil layer, which allows taking the no-contaminated sample, such as possible organic matter from the upper part.
- At each sampling point, approximately 250 g of soil was gathered and put into a tin can with a perforated lid. Before closing the tin can, the sample was diluted in water, filtered and preserved by way of a bactericide in order to avoid microbial degrading of the gases. With the same characteristics, an additional sample or safety countersample was taken, in case it would be needed to repeat the analysis or for an additional special analyses.

2) Data processing

- Chromatographic analysis of 600 samples of gas obtained from soil samples.
- Determination of the composition of these gases and quantifying their concentration.

- Determination of the genesis of methane through analysis of carbon isotopes.

3) Interpretation

- Revision of results on the data table.
- Determination of Bernard's humectation index, and estimation of the type of hydrocarbon (biogenetic/mixture or thermogenetic).
- Filtering of database.
- Statistical treatment.
- Determining of the depth constant, and of first and second order anomalous values for each one of the gasses (C1 to C5).
- C1, C2, C3, iC4, nC4, iC5 and C5 gas cartography and of overlying of C2 - C5 gasses.
- Evaluation of chromatographic profiles.
- Cartography and description of areas of interest.
- Determining and plotting of relations.

RESULTS

Chromatographic analysis

For this analysis, a Hewlett Packard series 5890 II chromatograph was used, equipped with a flame ionization detector (FID) and one PLOT capillary column, having a stationary stage of alumina of 50 m length and a 0.53 mm inside diameter.

The *ChemStation* program receives and integrates the signal sent from the gas chromatograph, identifies and quantifies the concentration and shows a graphic representation of the results (chromatogram). The light hydrocarbons in the sample (methane, ethane, propane, acetylene, isobutane, butane, isopentane, pentane and hexane) were quantified according to a certified standard. The equipment was calibrated every 15 samples, and a blank sample was run every 10 analyses. The data obtained from the chromatographic analysis were organized in tables, which were used for chromatographic profiles and interpretation. The interpretation took into account the following:

Determining of the background constant and anomalies was carried out based on statistical treatment. The obtained values are shown on Table 2.

Table 2. Values of anomalies.

Gas	Mean	Standard Deviation	2nd order Anomaly	1st order Gas anomaly
	μ	σ	$\mu + 2\sigma$	$\mu + 3\sigma$
Methane	156.33	332.73	821.79	1154.52
Ethane	4.93	9.57	24.07	33.64
Propane	0.43	0.47	1.37	1.85
Acetylene	0.06	0.17	0.40	0.58
Isobutane	0.02	0.04	0.11	0.15
Butane	0.23	0.67	1.57	2.23
Isopentane	0.37	2.05	4.47	6.52
Pentane	0.31	0.86	2.03	2.89
Hexane	0.11	0.18	0.48	0.67

Once the background constant and the grade of the first and second order anomalies were defined, contour and classes maps for all the thermogenetic gasses were elaborated. Figures 2, 3 and 4 show examples of the obtained maps:

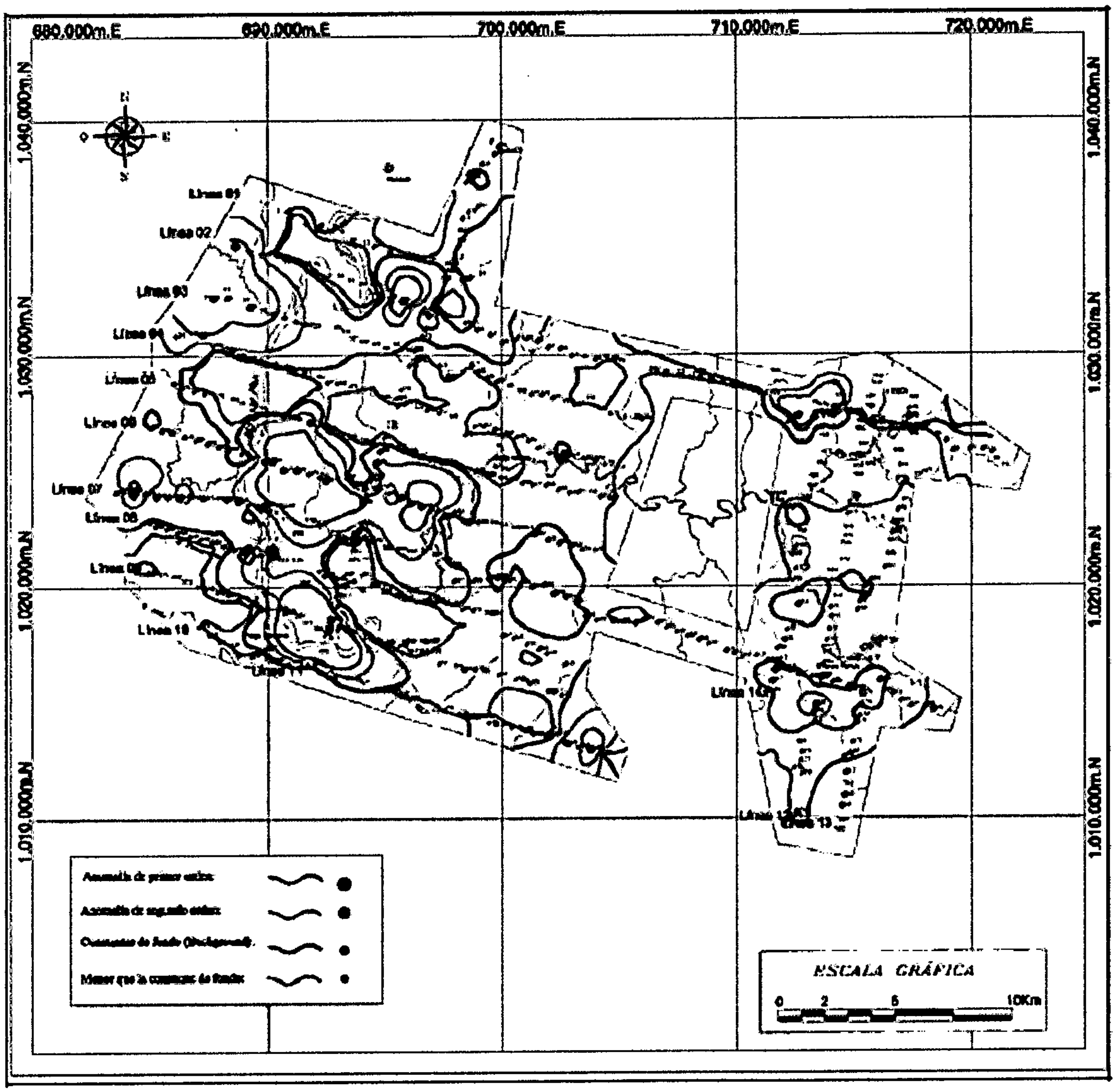


Figure 2. Map of clasess and contours of metane.

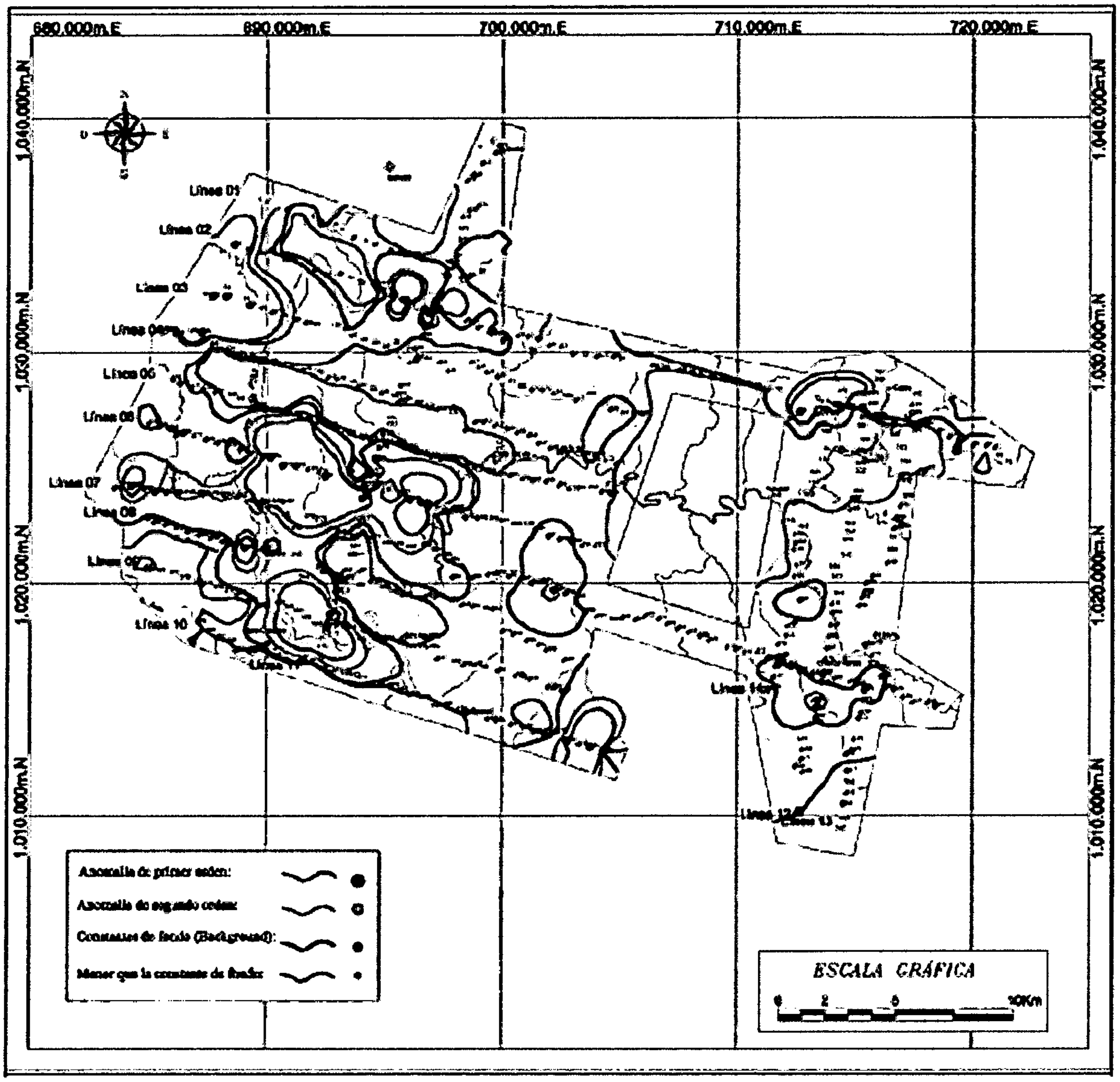


Figure 3. Map of clasess and contours of ethane.

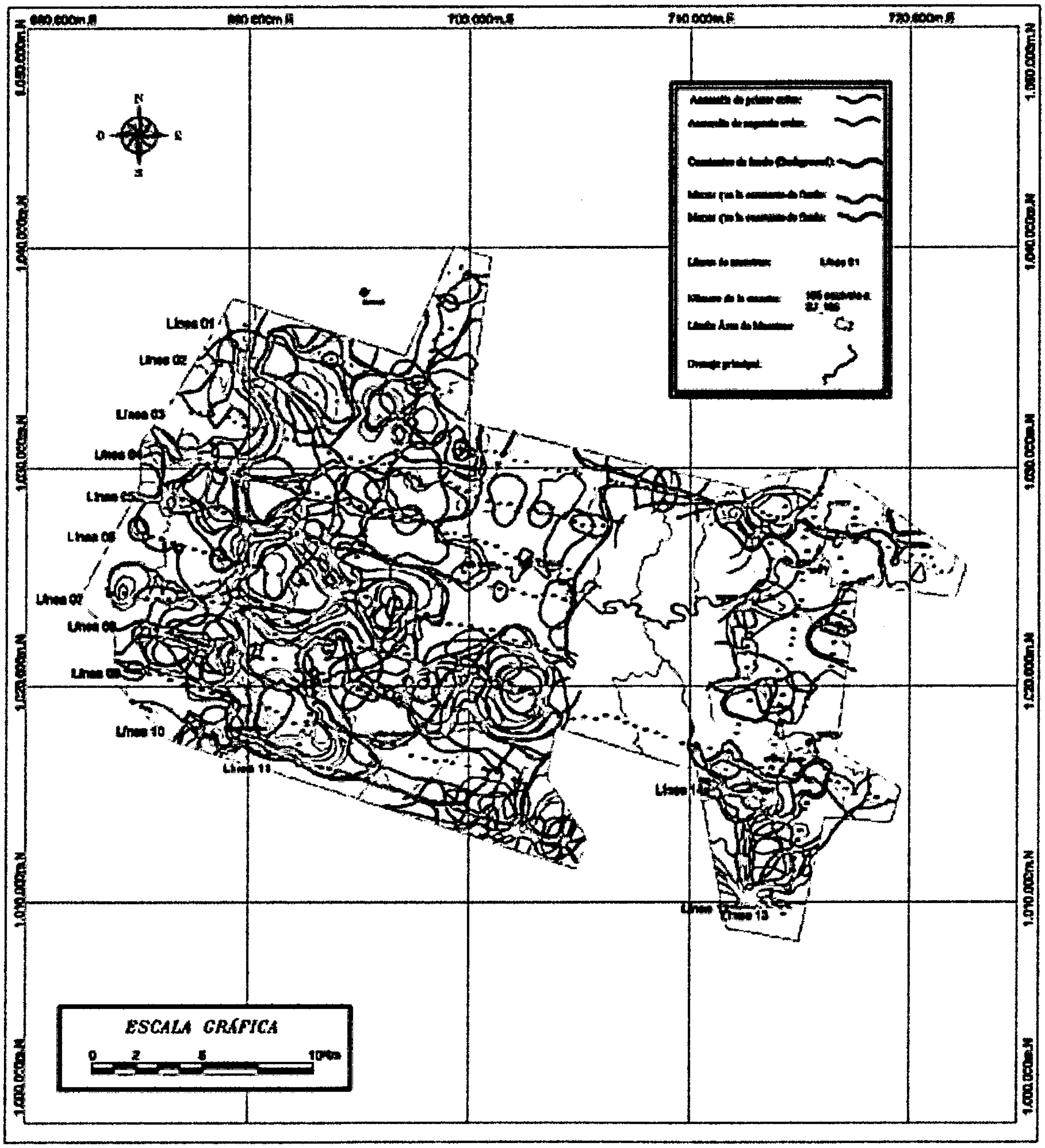


Figure 4. Map of supeposition of C2 to C5 contours.

The interpretation of the chromatographic data of the soil gas samples, evaluated in the present study, allows identification of 5 groups of anomalies (Figure 5).

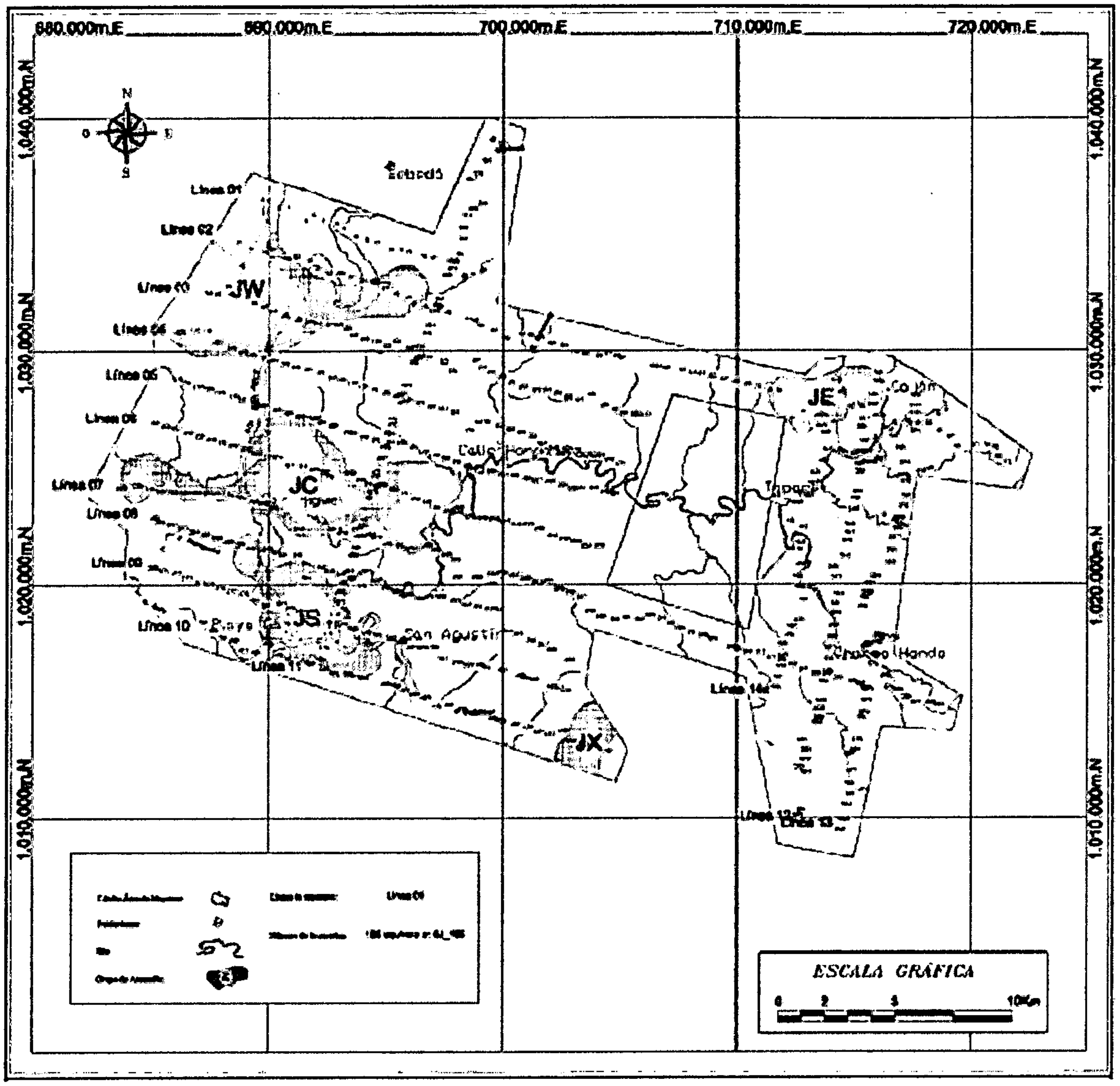


Figure 5. Map of areas of interest.

Hydrocarbons Origin

According to Whiticar (1994), the relative proportion of C1-C4 saturated alkanes within a gas sample provides an initial classification of the origin of gas. Bernard (1978), uses the C1/(C2 + C3) ratio for describing the humectation ratio, amongst others, of the surface emanation gasses and sediments and for estimation of their origin (Table 3).

Table 3. Ratio. Bernard's parameter.

Ratio (Barnard's Parameter)	ORIGIN			
	Biogenetic	Mixture	Diagenetic	Thermogenetic
C1/(C2+C3)	>1000	100 - 1000	50 - 100	0 - 50

By applying this ratio, 205 (1.5%) samples, amongst the total of the 600, were identified, distributed as follows: 81(13.5%) sample of gas of possible mixture; 364(20.6%) that would have diagenetic origin, being the rest (65.8%) of the gas samples, of thermogenic origin.

Lastly, based on considerations presented by Haworth et al. (1985), it is possible to estimate that the type of fluid, expected for this study area, would be predominantly liquid hydrocarbon and in a smaller proportion condensed and gas.

CONCLUSIONS

- The interpretation of the evaluated area in this study, allows identification of 5 areas with anomalous values of gases.
- It is possible to estimate that the type of fluid as expected from the area under study would be predominantly liquid hydrocarbon, condensate and gas.

REFERENCES CITED IN THE ORIGINAL WORK

Duchscherer, W. Jr. (1984). Geochemical hydrocarbon prospecting, with case histories: Tulsa, PennWell Publishing Co., 196 p.

Haworth, J. H., Sellens, M. and Whittaker, A. (1985). Interpretation of Hidrocarbons Shows Using Light (C1 – C5) Hidrocarbons from Mud – Log Data, AAPG Bulletin, V.69, No.8, pp. 1305-1310.

Isaaks, E. H. and Srivastava, R. M. (1989). An Introction to Applied Geostatistics.

Krumbein W. C. and Graybill, F. A. (1965). An Introduction to Statistical Models in Geology.

Schumacher, D. and Abrams M. A. (1996). Hydrocarbons Migration and its Near-Surface Expression, AAPG Memoir 66.

Whiticar, M. J. (1994). Correlation of Natural Gases with their Sources, Chapter 16, en Magoon L. B. and Dow. G. W., The Petroleum System – From Source to Trap, The Petroleum System: Memoir 60.

PETROGRAPHIC AND PETROPHYSICAL ANALYSIS OF OUTCROP SAMPLES OF GEOLOGICAL CARTOGRAPHY PROJECTS: ATRATO-SAN JUAN BASIN[1]

C & CO SERVICES LTDA.

www.cycoservices.com

2007

GENERAL OUTLINES

The intention of present work is to integrate the petrographic and petrophysical studies and analysis of samples and the geological, specifically sedimentological, information gathered in geological cartography projects, stratigraphical surveys and geological control in the seismic lines of the Atrao-San Juan Basin. The integration took effect for each reservoir formation of the Basin.

The rock samples of formations studied in this project mostly correspond to siliciclastic rocks and in less proportion calcareous rocks. The evaluation of the reservoir quality in every single formation allows getting from low to high, being rated the basin as moderate.

OBJECTIVE

To evaluate the reservoir quality of the basin by petrographic and petrophysical analysis.

METHODOLOGY

The following analyses and parameters for each reservoir formation were integrated and evaluated:

---

[1] Análisis petrográficos y petrofísicos demuestras de afloramiento de los proyectos de cartografía en: Cuenca del Ranchería-Cesar . Informe Final. C & Co Services Ltda. Agosto, 2007.

Petrographic: Depositional or detritus textures, diagenetical textures detritus composition or minerology, diagenetical composition or mineralogy, matrix types, cement types, porosity and pore types, porosity results (Petrograpical method or thin-section).

Petrophysical: Porosity, permeability, grain density, fluid saturation with retort.

Sedimentological: Lithofacies, lamination type or internal sedimentary structure, bioturbation and bioturbation intensity, stratigraphic column.

In order to classify the quality of the rock, the Winland correlation between porosity, permeability and the size of pore throat was applied, defining 5 categories to which different colours were assigned according to the following ranks:

Table 1. Criteria for the classification of samples by rock types

	Clasification	R35 Winland	Permeability
1	Very Goog	>8 µm	> 250 mD
2	Good	4 – 8 µm	50 – 250 mD
3	Regular	2 – 4 µm	10 – 50 mD
4	Bad	0.5 – 2 µm	1 – 10 mD
5	Very Bad	< 0.5 µm	< 1 mD

The Bioturbation levels mentioned in this report are according to the diagram shown in Figure 1.

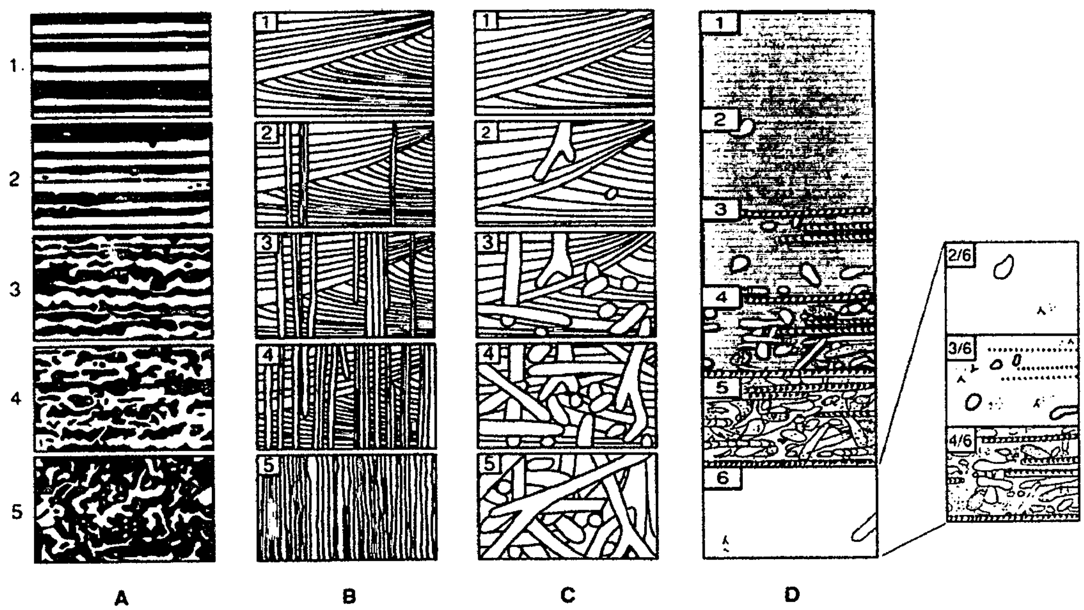


Figure 1. Schematic diagrames estimated from the bioturbation grade (ichnofrabric index). (A) Layers with thin lamination. (B) Layers with big thikness dominated by skoliths. (C) Layers with big thikness dominated by *Ophiomorpha*. (D) Deep water with fine grain environments.

Totally 126 samples were analized (Table 2).

Table 2. Analyzed samples from the Atrao-San Juan Basin.

FORMATION	ANALYSIS	
	PETROPHYSICS	PETROGRAPHY
Santa Cecilia La Equis	2	0
Iró	19	14
Itsmina	81	38
Conglomerados de La Mojarra	8	10
Condoto	12	4
Munguidó	1	0
Sierra	2	0
Penderisco	1	0
TOTAL	**126**	**66**

RESULTS AND CONCLUSIONS

Reservoir Quality

The rock samples of formations studied in this project mostly correspond to siliciclastic rocks and in less proportion calcareous rocks. The evaluation of the reservoir quality in every single formation allows getting from low to high, which means the basin's rate is a moderate quality.

The Istmina and Condoto formations show from very low to high porosity measures (0-35.7%) and from very bad to very good permeability (<0.002 - 519mD). The best samples are located in Tetado and Medio Tadó regions. The Conglomerados de la Mojarra and Penderisco formations show very good features but low data density, which does not allow conclude about the reservoir quality (Figure 2).

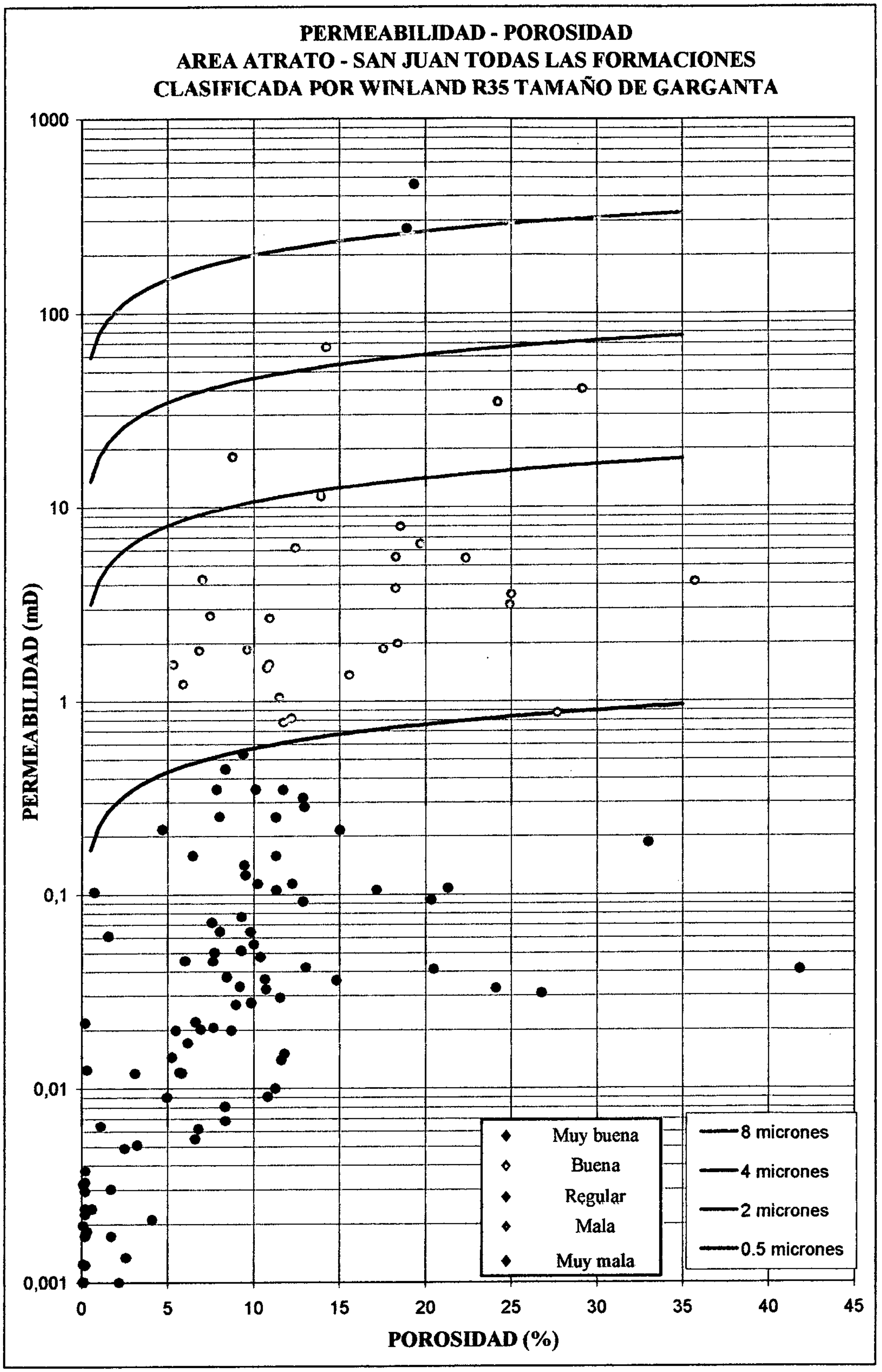


Figure 2. Porosity and Permeability of the rock samples from the Atrato-San Juan Basin.

The reservoir quality according to the formation is shown on the Table 3.

Table 3. Reservoir quality.

FORMATION	RESERVOIR QUALITY
Santa Cecilia - La Equis	Very low
Iró	Low
Itsmina	Regular – High
Conglomerados de la Mojarra	Regular
Condoto	High
Munguidó	Low
Sierra	Low
Penderisco	Regular

REFERENCES CITED IN THE ORIGINAL WORK

Folk, R. L., 1974, Petrology of sedimentary rocks: Austin, texas, hemphill's Book Store, 170 p.

DUNIA CONSULTORES LTDA, 2006. Cartografía geológica en el área de la subcuenca Atrato - San Juan, departamento del Chocó.

SEISMIC PROGRAM CHOCÓ 2D 2005[1]

BGP INC COLOMBIA BRANCH OFFICE

www.bgp-inc.com

2006

INTRODUCTION

The company BGP INC. Colombia Branch Office began activities before the seismic survey CHOCÓ 2D, during the first two weeks of January 2006. The design used in the project was the 25 m separation between receivers and 50 m between source points. The layout has 720 channels and a nominal covering of 180. The original design of the program, which considered 5 seismic lines (ANH-CHBN-2005-01, ANHCHBN-2005-02, ANH-CHBN-2005-04, ANH-CHBN-2005-06 and ANH-CHBN-2005-08) covered a total of 378.00 km (Figure 1). Nevertheless, because of topographic factors, and public order problems, finally the covered length was 336.850 km. On December 28, 2005 the recognition of the area of the program on the northern part began, which was complemented with the previous consultation with the black and indigenous communities and the request of authorities. The topographic survey of the area started on March 17, 2006 and ended on August 21, 2006. 7643 out of 8005 planned shot points were drilled between April 27 and October 28. The recording operations carried out with Sercel 408 XL equipment started June 8, 2006 and end on November 30.

As a complementary activity to the seismic study, the geological survey of the lines was executed by ESAG (Environmental and Geophysical Studies) enterprise.

LOCATION

[1] Programa Sísmico Chocó 2D 2005. Reporte Final de Operaciones. Diciembre, 2006.

The seismic program is located to the south of the Chocó Department, in the jurisdiction of Bagadó, Tadó, Río Iró, Condoto, Nóvita, Sipí, Medio San Juan, Istmina, Río Quito, El Cantón de San Pablo (Managrú), Unión Panamericana, Cértegui, Pie de Pato (Alto Baudó), Medio Baudó and Bajo Baudó municipalities (Figures 1 and 2).

Figure 1. Location of the Seismic Program CHOCÓ 2D area.

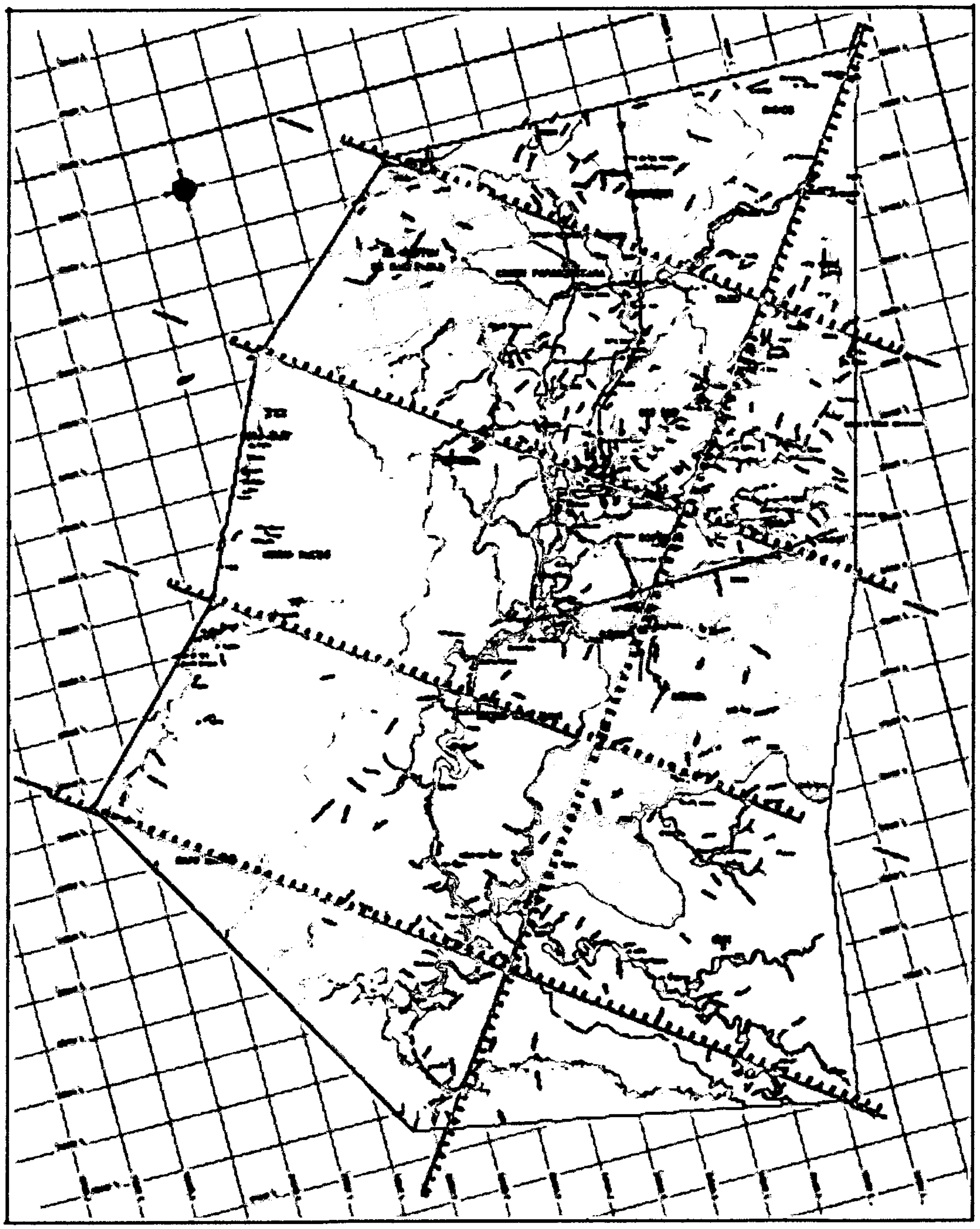


Figure 2. Detailed location of the area of the seismic program.

The study area of the seismic program is characterized by plain, undulating, and uneven terrains because of the direct influence of the valleys, generated by the modeling of San Juan, Baudó, and Atrato rivers. The raises of the land hold minimum values of 2.31 m.a.s.l. and maximum of 1180.84 m.a.s.l..

METHODOLOGY

Logistics and Operation

The sequence of the working process was executed as foll:

- Recognition of the area.
- Census of the properties in the area.
- Request of authorizations.
- Establishment of the GPS network support.
- Adaptation of the lines.
- Topographic survey.
- Drilling of wells.
- Seismic data acquisition.
- Payment of affectations.
- Reinstatement of mobile camps, heliports, unloading zones (UZ), and restoration of lines.
- Preliminary data processing.

The final adjustment of the GPS network was executed with the module of network adjustment, fixing the origin for geodesic coordinates and ellipsoidal heights in the MAGNA 3W Reference System (ITRF; time 1995.4; ellipsoid GRS80) of the VERTEX IGAC GPS-T-CH-2. Figure 3 shows the main network and distribution of the GPS points defined for the seismic program.

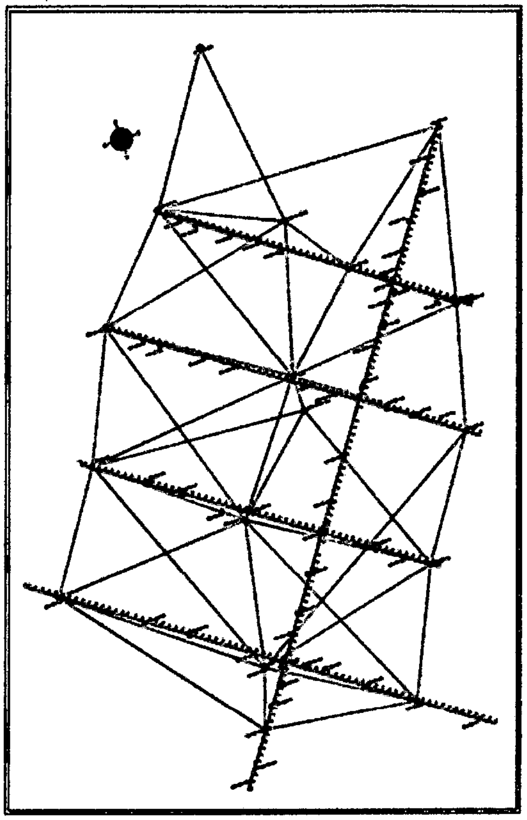


Figure 3. Design of the GPS network.

General data of the program

The chronological and statistical details of the program are shown in Table 1.

Table 1. General details of the project.

DETAIL	TOTAL
Date of beginning	March 6, 2006
Date of beginning of leveling	March 17, 2006
Worked days of leveling	158 days
Leveled kilometers	406275
Date finalization last day of report	August 21, 2006
Theoretical receiver points	16925
Leveled receiver points	15023
Theoretical wells	8005
Leveled wells	7471
Leveled production kilometers	336848 km
Skip wells	0
Skip receivers points	257
Average km / group / leveling day	0.377
Solar observations executed	410
Source points moved greater than 6.50 m	2373
Additional source points	129

Drilling and Loading

Once the seismic lines were leveled, the topographic information was delivered for drilling and loading of the shot points (Table 2).

Table 2. Pre plot design of the seismic program for drilling stage.

TOTAL PRE-PLOT WELLS SEISMIC PROGRAM			
LINE	**PRODUCTION WELLS**	**OTHER WELLS**	**TOTAL WELLS**
ANH-CHBN-2005-01	2345	88	2433
ANH-CHBN-2005-02	1003	88	1091
ANH-CHBN-2005-04	1277	88	1365
ANH-CHBN-2005-06	1309	88	1397
ANH-CHBN-2005-08	1631	88	1719
TOTAL	**7565**	**440**	**8005**

Experimental Test

For determining the depth and ideal size of load for the seismic program, a test in the line ANH-CHBN-2005-02 was carried out and the wells were drilled according to the parameters showed on Table 3.

Table 3. Parameters of depth and size of load for the experimental test.

OPTION	1	2	3
DEPTH (ft)	30	36	39
SIZE OF LOAD (g)	3600	4500	5400

From the combination of these parameters 9 mini-hole type wells and 18 deep wells were obtained (3x10 ft), for a total of 27 wells. The distribution of parameters along the lines of the seismic program can be seen in Figure 4. A total of 7642 wells were drilled in the five lines.

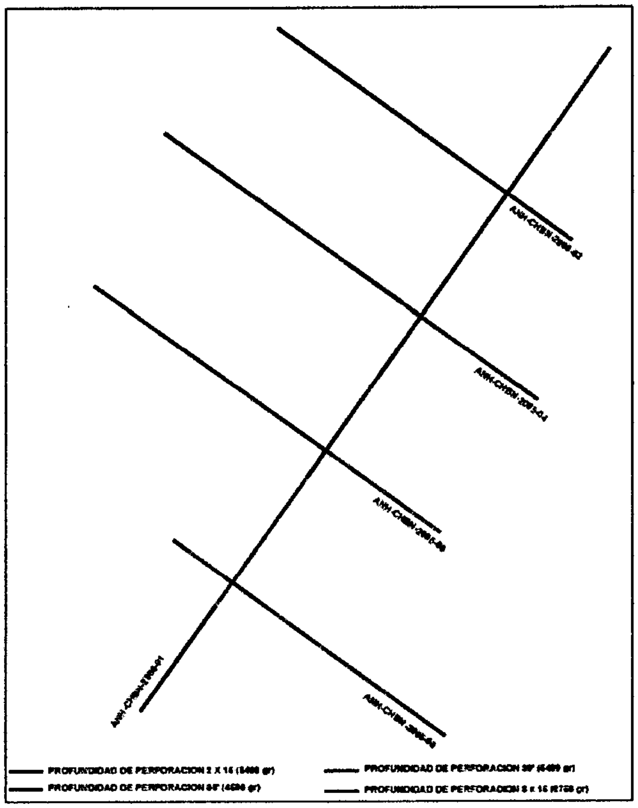


Figure 4. Distribution of drilling patterns in the area of the seismic program.

Explosive Material

The explosive material, sismigel, manufactured by the Industria Militar Colombiana (Colombian Military Industry) "INDUMIL", is a charge of emulsion type placed in a hermetically sealed plastic container. The emulsion is chemically compounded whith a great percentage of nitrocarbonites, that makes it a material of non-contaminant nature when it gets decomposed. It has high speed of detonation, generating pulsation of strong, acute seismic energy, and of a good definition. It requires the usage of seismographic detonators. Their handling is safe because of the low sensibility to rubbing and to the impact. It is a dense explosive, easily submergible in water. It comes in packs of 450 g, 900 g and 1800 g. Table 4 synthesizes the most important characteristics of the explosive material.

Table 4. Technical specifications of Sismigel.

TECHNICAL CHARACTERISTICS OF SISMIGEL		
Density	g/cm3	1.21+/- 0.02
Speed of Detonation	m/s	5500 +/- 500
Absolute Power of Volume	cal/cm3	1.006
Absolute Power in weight	cal/g	838
Relative Power in volume		1.33
Resistance to Humidity		Excellent
Resistance to Hydrostatic Pressure	2kgf/cm2	Good

Detonators

Percussion caps manufactured by the enterprise "FAMESA" and detonators with length of cable of 4 m and 17 m were used, depending on the arrangement of drilling. The Table 5 summarizes the most relevant aspects of the percussion cap.

Table 5. Technical specifications of the electrical detonators.

TECHNICAL CHARACTERISTICS OF THE DETONATORS		
Average time of initiation when applying an electrical current of 2 A		Less than 1 ms
Resistance to the hydrostatic pressure during two hours	(kg/cm^2)2Hr	6.8
Diameter of the socket	mm	6.3
Test of ESOPO, diameter of drilling (mm)	mm	10
Resistant to the impact	(2kg/m)	Does not detonate
Volume	(cm^3)	28
Electrical resistance of the cable	(Ω/m)	0.053

Data Acquisition

The seismic program acquisition parameters are described in Table 6.

Table 6. Technical parameters.

Data acquisition system	Sercel 408XL
Numbers of channels	720
Blaster	Pelton "Shotpro"
Auxiliary channels	Two (2) Auxiliary 1. Auxiliary Time break 2. Confirmation of the time break, and two seconds analogical Up Hole.
Low cutting filter	Out
High cutting filter	0.8 Frequency Nyquist linear
Notch Filters	Out
Sampling interval	2 ms
Acquisition format	SEG-D
Acquisition time	12 seg
Load size	4500 g, 5400 g, 6750 g
Load type	Sismigel
Interval between wells	50 m
Load depth	3.3 m, 7.9 m, 8.8 m
Receivers separation	25 m
Geophone geometry	Centered in the stake
Shot points location	Centered in the stake
Geophones type and frequency	GS-30 CT, 10 Hz
Geophones per group	A series of 6 geophones

The stage of data acquisition was carried out once the seismic lines had been drilled. A digital equipment of cable telemetry (24 bits) was used (SERCEL 408XL version 7.1.42).

The technical specifications of the data acquisition system are shown in Table 7.

Table 7. Specifications of Sercel 408XL seismograph.

DESCRIPTION	SERCEL 408XL
Channels (Maximum)	20000
Converter A/D	24-bit
Pre-Amplifier (dB)	0 and 12
Sampling time (milliseconds)	0.25, 0.5, 1, 2 and 4
Total Dynamic Range	140 dB
Equivalent noise with the open inlet to 48dB(RMS)	0.20 uV
Distortion	0.00%
Average gain precision	0.10%
Rejection in common mode (CMR)	>110 dB
Induction isolation (Crossfeed)	>110 dB
Anti-aliasing filter in min. stage at 2ms	200 Hz, 73 dB/Oct.
Inlet impedance in differential way	20 kΩ

Sequence of Processing

The following sequence was applied:

- Conversion of format SEG-D to format SDA: reading of cartridge 3490E is carried out, as well as conversion to internal format SDA automatically without original changes.
- Geometry definition, application, and checking: execution of the geometry steps, which is applied to the data. The records are checked one by one and on the screen.
- Traces balance: consists in the application of time power based upon a gain of 2 dB.
- Trace editing: determination of noisy traces and putting them in one file.
- Pre filter: consists in the delimitation of ranges of frequencies with band pass filter between 6 and 65 Hz; change of sampling rate: from 2 ms to 4 ms.
- AGC application: automatic gain correction calculated in a window of 700 ms, 4 dB, and pre-whitening 0.001.
- Elevation correction: a 1000 m datum was used and Vo = 2000 m/s.
- Refraction statics: first arrivals picking, and calculation of statics applied to receivers and shot points.
- Surface consistent amplitudes correction: calculated in a range of relative amplitude with minimum of 0.01 and maximum of 12 with 25 iterations.
- Deconvolution: spiking deconvolution was applied to the data with length of operator 400 ms, pre-whitening 0.01 and window until 6 s.
- Noise attenuation: was applied between beginning and end between frequencies from 0 Hz until 25 Hz with a cut limit of 2000 ms.
- CDP ordering.
- Velocity analysis.
- NMO correction and stacking.
- A band pass filter of 0 to 12 s was applied, an AGC of 700 ms and coherence in the FX domain.
- Files generation and plotting.

Technical Parameters

The technical parameters the seismic program CHOCÓ 2D 2005 was executed with, are described in Table 8.

Table 8. Technical parameters of the seismic program.

Distance between receivers	25 m
Distance between sources	50 m
Top of load (according to the arrangement)	8.8 m
Size of load (according to the arrangement)	5400 g
Total channels per record	720
Minimum offset	12.5 m
Maximum offset	8987.5 m
Geophones per line	6 (1 series of 6 Geophones) GS 30CT
Type of spread	Roll On / Roll Off
Covering in the subsoil-Fold	180 Nominal
Covering at beginning and end of line	135

RESULTS

Stratigraphy

Sedimentary rocks from the Paleogene and Neogene, igneous rocks that correspond to the economic basement of the basin, and intrusive bodies crosscutting the sedimentary sequence have been observed along the seismic lines of the Seismic Program CHOCÓ – 2D 2005. Considering the location in which the project is developed, we have adopted the stratigraphic nomenclature used by the ANH corresponding to the San Juan River Valley Basin (Table 9).

<table>
<tr><th colspan="6">COLUMNA ESTRATIGRÁFICA GENERALIZADA
Cuenca del San Juan</th></tr>
<tr><th colspan="3">EDAD</th><th colspan="3">Unidad Estratigráfica</th></tr>
<tr><td rowspan="5">NEÓGENO</td><td>Plioceno</td><td></td><td colspan="3">Fm. Atrato</td></tr>
<tr><td rowspan="4">Mioceno</td><td>Tardío</td><td colspan="3">Fm. Munguidó</td></tr>
<tr><td rowspan="2">Medio</td><td rowspan="3">Grupo San Juan</td><td colspan="2">Fm. Condoto</td></tr>
<tr><td colspan="2">Fm. Conglomerados de La Mojarra</td></tr>
<tr><td>Temp.</td><td>Fm. Istmina</td><td>Compl. Ultramáf. zonado del Alto Condoto</td></tr>
<tr><td rowspan="5">PALEÓGENO</td><td>Oligoceno</td><td></td><td colspan="3">Fm. Sierra</td></tr>
<tr><td rowspan="3">Eoceno</td><td>Tardío</td><td rowspan="4">Fm. Iró</td><td rowspan="2">Miembro Superior
Miembro Medio</td><td rowspan="4">Batolito de Mandé</td></tr>
<tr><td>Medio</td></tr>
<tr><td>Temp.</td><td rowspan="2">Miembro Inferior</td></tr>
<tr><td>Paleoceno</td><td>Tardío</td></tr>
<tr><td colspan="3">CRETÁCEO TARDÍO</td><td colspan="3" rowspan="2">Complejo Santa Cecilia – La Equis /
Grupo Cañasgordas (Fm. Penderisco / Fm. Barroso)</td></tr>
<tr><td colspan="3">PRE – CRETÁCEO</td></tr>
</table>

Tab. 9. Generalized stratigraphic column of San Juan River Valley Basin.

Structural Geology

The Atrato-San Juan Basin is a depression in N-S direction, characterized by negative gravimetric anomalies that decrease towards the south, starting off at values of 0 mGal in the north around Río Sucio, with values of – 50 mGal in the Quibdó area, and reaching up to – 90 mGal in the south of the basin around

Buenaventura. This data have been interpreted as a thickening of the sedimentary cover towards the south, possibly reaching 10000 m of sediments deposited on the oceanic crust (Case et al, 1971).

This thick sedimentary cover is the result of multiple and complex tectonic processes that have affected the extreme NW of South America. This area is characterized by the convergence of the Nazca, Caribbean and South American plates and forms a structural complex of terrains rose along various fault systems. More specifically, in the San Juan Basin, we can observe an accretion prism as the result of a subduction process that includes the sediments deposited in the forearc basin, and segments of the oceanic basement, developing a west-northeast vergent imbricate fan. This fan may have an important N to NE course component, as a result of a possible process of oblique subduction that led to the development of megafaults with dextral displacement (Aspden, 1984 en Zapata, 2001; Barrero et al, 2006) (Figure 5).

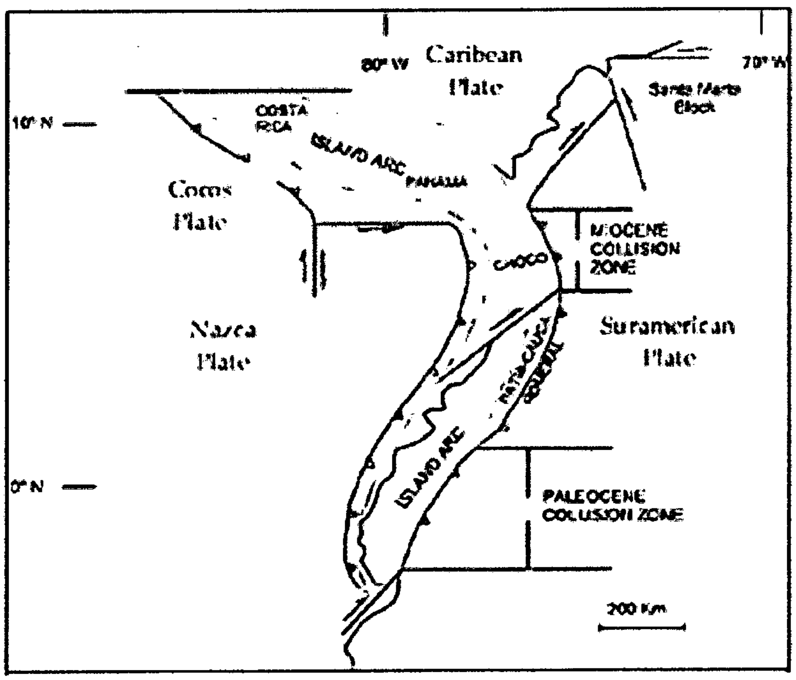


Figure 5. Schematic collision model.

Structurally, the area of interest can be divided into two main regions that are very different. In the west, there is an area of vast and soft structures that corresponds to the south of the Chocó Block described by Duque-Caro (1990) and that according to Cossio (2003) structurally belongs to the Atrato Basin. In the east, we find a very interesting area from the structural point of view in which a west-vergent imbricate fan develops across "Istmina Deformed Zone" (Duque-Caro, 1990) to the foothills of the Western Cordillera.

The structural elements observed on the field let us to identify the existence of various structural styles in the study area. Considering that the geological study was carried out upon the seismic lines, each of them was subdivided in various *zones*, which corresponds to a structural style with specific characteristics. For the lines with NW-SE direction (lines ANH-CHBN-2005-02/04/06/08), 3 structural zones were described: an external or western area, a central one that corresponds to the Istmina Deformed Zone, and an eastern zone that includes the western foothills of the Western Cordillera. For the line, ANH-CHBN-2005-01, that has a direction NE-SW and crosses the axis of the eastern zone, 2 structural zones were defined: in the north, including "Istmina Deformed Zone", and the second in the south, where few structural elements exist (Figures 6 and 7).

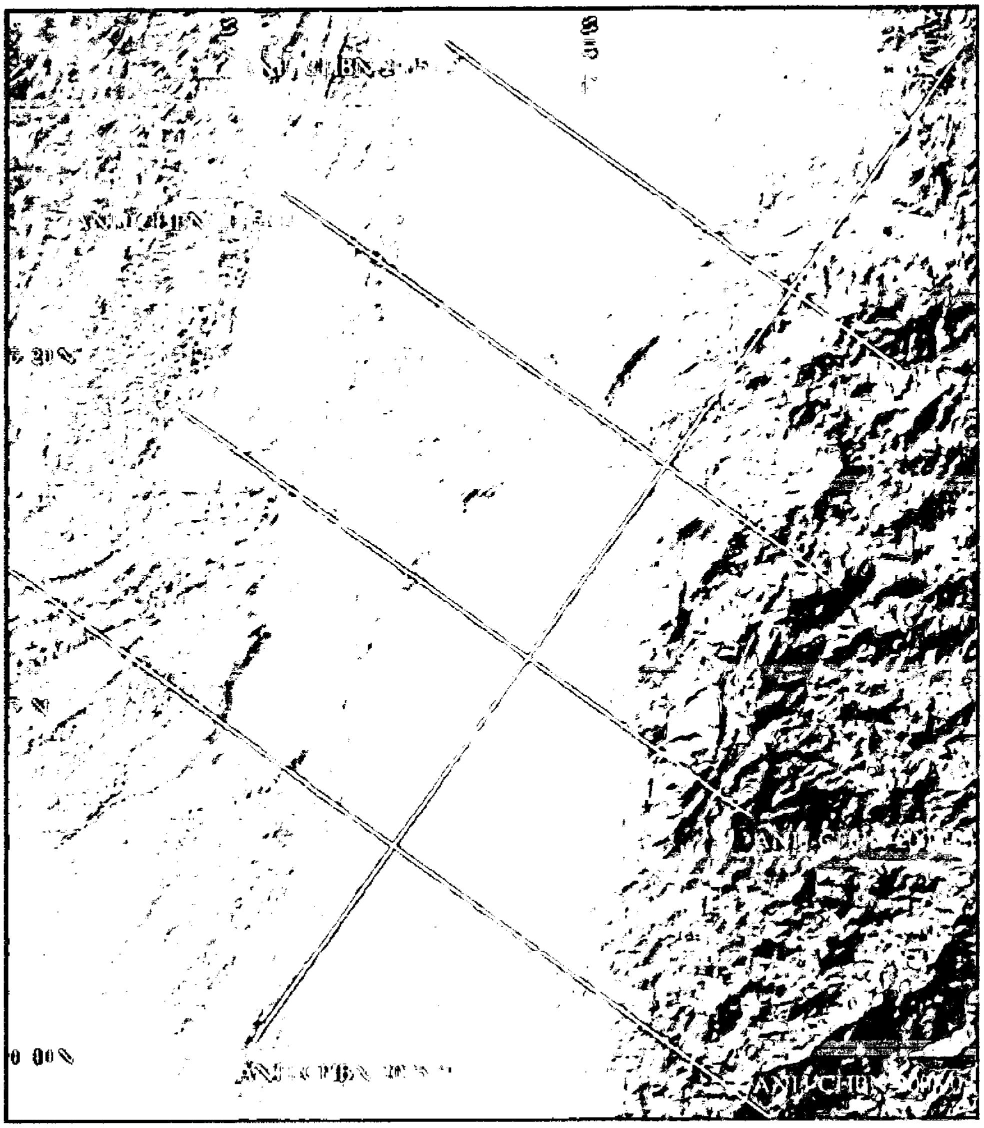


Figure 6. Radar image of the study area, western side of the Western Cordillera. Principal structural elements are highlighted.

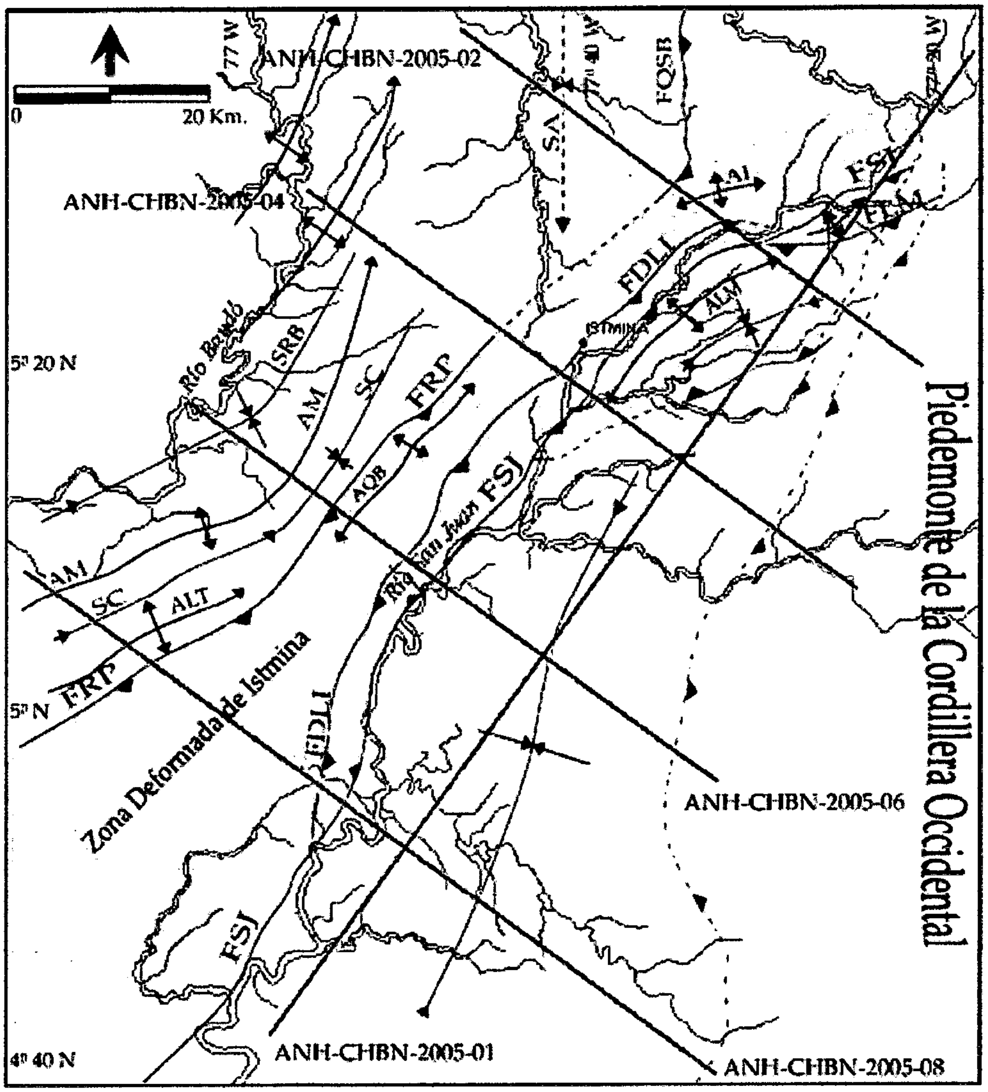


Figure 7. Schematic image with highlighted structural elements. FRP-Pepe River Fault, FQBS-Santa Barbara Brook Fault, FDLI-Dipurdú de los Indios Fault, FSJ-San Juan Fault, FLM-Las Mojarras Fault, SRB-Baudó River Syncline, AM-Misara Anticline, SC-Capiró Syncline, ALT- Trojilla Anticline, AQB-Quebrada Beriguadó Anticline, AI-Ibordó Anticline, SA-Atrato Syncline, ALM- Mojarra Anticline. The Istmina Deformed Zone is shown in grey.

Discussion

Considering the tectonic context of the San Juan Basin and the observations made on the field along the 5 seismic lines, we proposed a model of imbricate fan with thrust faults in N-NE direction and with a W-NW vergence. This imbricate fan extends from the front of the thrust fault, which corresponds to the Pepe River Fault and its continuation towards the north (Santa Bárbara Brook Fault), till the high angle reverse faults in the foothills of the Western Cordillera.

Studies also suggested that there is a displacement component in a dextral direction on the high angle faults of the Western Cordillera Foothills. This can be seen by the stacking of rocks in the north against San Juan Fault System, where a block has risen letting more ancient rocks of the sedimentary filling come to the surface (Iró Formation).

This strike-slip displacement is also shown by the thinness of the *central zone* towards N-NE, as well as by the development of high angle thrust faults that cross each other, and lead to a change in the dipping direction, and the development of retro-overthrusts (e.g. Docampadó Fault).

Moreover, the displacement of material towards the north leads to decrease in stress in the south, which has manifested itself as the development of a depression between the San Juan Fault and the Western Cordillera Foothills, and the broadening of the *central zone* towards the west.

This compressive stress is associated with a strike-slip displacement result in the "Istmina Deformed Zone", which affects rocks anterior to the Middle Miocene (Iró Formation, Sierra Formation, and San Juan Group). This indicates a tectonic process that did not affect rocks posterior to Middle Miocene (Munguidó and Atrato formations and recent deposits).

It is important to highlight that we omit the continuation of Las Mojarras Fault towards the south, as interpreted in previous studies (e.g. Cossio 2003) considering that only a lithologic change was proved between the Iró and Istmina formations, in the north of the study area, where the fault presents a NNW vergence.

Petroleum Geology

In the San Juan Basin, no exploratory wells have been drilled. Therefore the existence of deep deposits cannot be confirmed. Nevertheless, various preliminary studies have been carried out indicating the existence of all the necessary elements to assume that the basin presents a good potential for the generation and accumulation of hydrocarbons.

In the following, we describe the main elements of the petroliferous system, including observations made on the field, and in previous studies (e.g. Rodríguez, 1990; Suárez, 1990; Peña, 1996; Mera and Piragua, 2001).

Source rock

The fissil black lodolites (shales) and limestones from the Iró Formation have been considered petroleum-generating rocks in the San Juan Basin. According to geochemical studies, they indicate that the quantity of organic matter is adequate for generation of petroleum (Peña, 1996).

Reservoir rock

The main exploratory goal is to be focused on the fractured cherts and calcites of the Iró Formation. Considering the rheology of this unit and the intense tectonic processes to which it has been exposed, the rocks of the Iró formation develop a broad system of fractures that can have high values of secondary porosity and permeability.

Other rocks with the potential to store hydrocarbons correspond to the leyers of sandstone and conglomerates inserted in the Sierra, Istmina, Condoto and Munguidó formations, and especially the thick sequence of conglomerates in the Conglomerados de la Mojarra Formation. However, according to observations, there are high contents of mud-size matrix in the sandstone, which could reduce the values of porosity and permeability.

Rodríguez (1990) and Peña (1996) describe the existence of sandstone with primary porosity greater than 10 % in the Iró Formation, and, although permeability is low, it can be increased by fracturing of this unit.

Seal rock

Seal rocks correspond to the leyers of lodolites, sandstone lodolites, and calcareous lodolites from the Sierra, Istmina, Condoto and Munguidó formations.

Trapping

Considering the existence of an east vergent imbricate fan, the principal type of traps that should be found are structural, with the development of anticlines at different scales, associated with the displacement over thrust faults in depth. Locally, we can suppose the existence of stratigraphic traps, especially associated to the conglomerate sequences deposited in the Western Cordillera Foothills.

Therefore, there can be three interesting exploratory plays. The main one corresponds to the southern region of the eastern structural zone (Figure 9) that presents a vast syncline towards the south. It is covered by the discordant deposits of the Atrato Formation, and in depth it may maintain the structural trend of the basin with an imbricate fan composed of overthrust faults with a W-NW vergence, that folds over the whole sedimentary sequence. The potential of this play is confirmed if we take into consideration that the block of the "northern zone", in which the Iró Formation outcrops, is structurally separated from the "southern zone", hindering the migration and the possible loss of hydrocarbons by exposure on the surface of the Iró Formation.

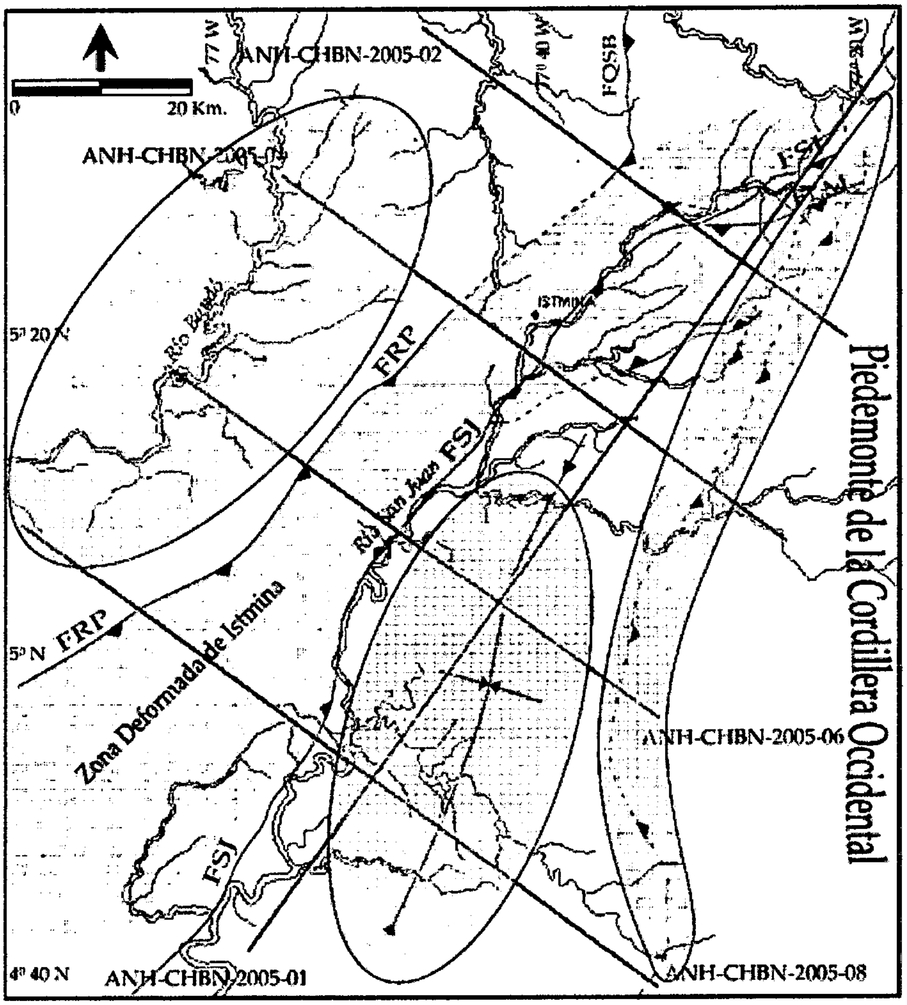


Figure 8. Main plays in the study area. FRP-Pepe River Fault, FQBS-Santa Bárbara Brooks Fault, FDLI- Dipurdú de los Indios Fault, FSJ- San Juan Fault, FLM- Las Mojarras Fault. The Istmina Deformed Zone is shown in grey.

The second exploratory play corresponds to the western structural zone (Figure 8), composed of vast and continuous structures, that do not seem to be affected by faults or major fracture systems that might lead to the migration or possible loss of hydrocarbons. In depth this zone must present continuous sedimentary records and, given the existence of large structures with pitch to the N-NE, it suggests the existence of good traps in depth for the Iró Formation.

The third exploratory play corresponds to the subthrust zone of the Western Cordillera Foothills, in which the Iró Formation must be found below the high angle overthrust faults that rise the basement (Figure 8). Given the location of the faults, the rocks of the Iró Formation must present a high fracturement, which increases the secondary porosity and permeability. On the other hand, it is difficult to define the location of deep faults and there may be a need to drill rocks of the basement.
It has to be mentioned that we are omitting the so called "Istmina Deformed Zone" given that in the north the Iró Formation outcrops, whereas in the south, along the central structural zone (Figure 8), there are small structures of little continuity, crossed by a large number of faults and fracture systems that facilitate the possible migration and loss of hydrocarbons.

CONCLUSIONS

- Based on the observations made on the field and previous geological studies, we consider that the study area is located on an imbricate fan with a W-NW vergence that corresponds to the Western Cordillera Foothills, which itself shows a major course component attributed to a process of oblique subduction.
- The study area of the Seismic Program CHOCÓ – 2D 2005 is located north of the San Juan Basin, which corresponds to an extended and deep depression, filled with a thick sedimentary sequence of the Cenozoic. It starts on the western foothills of the Western Cordillera towards the south of the Dabeiba Arch and broadening in NNE-SSW direction, and extending towards the Pacific Ocean.
- The location of the study area in the San Juan Basin made possible the identification of various types of lithologies, among which we can find rocks of the basement, which appear on surface in the Western Cordillera foothills and which correspond to the units Santa Cecilia-La Equis Complex, and Cañasgordas and Batolito de Mandé groups.

- "Santa Cecilia-La Equis Complex" is essentially composed of agglomerates, basalts and locally some intercalations of sedimentary rocks.
- "Cañasgordas Group", from late Cretaceous, is divided in two formations: Barroso and Penderisco. The Barroso Formation is mainly composed of diabases, although there are also basalts, breaches, agglomerates, and intrusive rocks. From the Penderisco Formation, the Urrao Member can be seen on the surface; it is mainly composed of black lodolites, that show incipient foliation, and locally it is possible to find massive tobaceous sandstones.
- "Batolito de Mandé", from Paleocene to Eocene, is mainly composed of diorites and locally, porfiritic basalt dikes, and/or andesites.

- Among the rocks of the sedimentary filling in the basin, we have identified the Iró and Sierra formations, the San Juan Group (composed by Istmina, Conglomerados de la Mojarra, and Condoto formations), the Munguidó and Atrato formations, and, finally, quaternary deposits.
  - The Iró Formaton, Paleocene to Eocene, is composed of limestone intercalations, chert, siliceous lodolites from light grey to black and sporadically purple, deposited in an open sea context. It acts as a generating rock in the San Juan Basin, and as the main reservoir rock given its high secondary porosity. It presents the only inactive filtration source that corresponds to an outcrop of light pink cherts with dry petroleum stains filling up the fractures.
  - The Sierra Formation, from the Oligocene age, consists of an intercalation of calcareous lodolites, calcareous sandstones, limestones, and sandstones as a matrix of polymictic conglomerates supported towards the base (?).
  - The San Juan Group, from early to late Miocene, is composed of various formations (Istmina, Conglomerados de la Mojarra, and Condoto). It was deposited in a fluvial environment below sea level (*lowstand*), close to the coast. It deepens towards the west and shows more detailed coastal

environment and is easily affected by variations of the sea level. It shows an increase in calcareous mud,and the presence of layers of limestones.

- The Istmina Formation, of early Miocene, consists of a monotonous sequence of muddy sandstones, sandy lodolites, and well-consolidated polymictic conglomerates, with abundance of carbonaceous material and thin layers of carbon, that reduce in the west, as the calcareous content increases, resulting in layers of limestone and the development of calcareous concretions.

- Based on observations made on the field and with the help of satellite images and previous studies, the study area can be divided in three main *structural zones*:
  - *Western zone.* This corresponds to the western area of the Pepe River Fault and its continuation towards the north in the Quebrada Santa Bárbara Fault, corresponding to the front of the W-NW vergent over-thrust that characterized the San Juan Basin. In this area, we have observed a sedimentary filling affected by large structures, with soft dip slopes; there is no sign of faults on the surface. The interpreted geometry of the folds suggests the displacement over the east vergent faults in depth, attributed to the obduction and rising of "Serranía del Baudó".
  - *Central zone.* It corresponds to the "Istmina Deformed Zone", in the area between the thrust fault with a W-NW vergence in the west, and the San Juan River Fault in the east. It acts as a W-vergent imbricate fan; it presents folds that are relatively short and tight as a result of deep west vergent overthrust faults and east vergent retro-overthrust, with strong inclinations and predominant N-NE direction.
  - *Eastern zone.* This corresponds to the eastern area of the San Juan Fault, including the Western Cordillera Foothills. It is divided in two areas: the *northern zone*, which is the NE extension of "Istmina Deformed Zone", where we can observe a dextral displacement over the faults of the basement that leads to the "stacking" and rising of a block in which the Iró

Formation is visible on the surface. The *southern zone* corresponds to a vast syncline that deepens towards the south from "Istmina Deformed Zone". In general, it is characterized by the development of soft structures with constant and low-angle dip slopes, between 10° and 30°.

- *Conglomerados de la Mojarra Formation,* from end of early Miocene to middle Miocene, acts as a big lens that gets thinner towards the west; it is composed of a monotonous succession of thick and well consolidated conglomerates, with clasts rounded cherts, limestone, sandstones, limolites, quartz diorites and volcanic rocks, which float on a thick grain sand matrix, with sporadic calcareous cementation.
- *The Condoto Formation,* from middle Miocene, is characterized by an intercalation of sandy lodolites and grey muddy sandstone, with well consolidated polymictic conglomerates packets, that decrease towards the west, as well as intercalations of limestone that increase towards the east. Locally plant fossils can be found.
- *The Munguidó Formation,* from late Miocene, is composed of intercalations of grey sandy lodolite packets, grey and yellowish muddy sandstones, conglomerated sandstones, and polymictic matrix-supported conglomerates. Locally there are plant fossils, bivalves and gastropods.
- *The Atrato Formation,* from Pliocene, corresponds to an ancient level of terrace, constituted of poorly consolidated rocks, ranging from lodolites to polymictic matrix-supported conglomerates. Locally, partially carbonized trunks can be found.
- There are three intrusive rocks corresponding to gabbros, associated with the Alto Condoto Ultramafic Complex, dated from the early Miocene. This could prove the subduction process of the Farallon Plate under the South American Plate, and the high tectonic activity occurred at the end of early Miocene.
- The Conglomerados de la Mojarra Formation can correspond to a syntectonic unit deposited as a result of the Iró Formation rising, what

would explain its lithology, formation environment, and location in a transition area between the southern and northern zones. Also, the depositation and distribution of this unit, thinner towards S-SW of the rising block of the Iró Formation, is consistent with the existence of a dextral direction component on the Western Cordillera Foothills.

- Thus, the San Juan Basin and in particular the area of the Western Cordillera Foothills, has been affected by compressive tectonics, following a subduction process, with a very important event occurred at the end of early Miocene and the beginning of middle Miocene, that may have started with a dextral displacement over a fault in the base of the foothills, followed by (and maybe in a synchronic way) reverse displacements that led to a NW vergent imbricate fan, that got "stacked" in the north of the area, causing the formation of the so-called "Istmina Deformed Zone'. As a result of the rising produced in the northern zone and syntectonically (?), the Conglomerados de la Mojarra Formation had deposited as a large alluvial fan.

- All the elements of the petroliferous system are present. The Iró Formation corresponds to the generating rock and the main reservoir rock, due to the high fracturement of this unit. There are also secondary reservoir rocks associated with the leyers of conglomerates and sandstones from the Sierra Formation, San Juan Group, and Munguidó Formation. There are multiple layers of seal rocks, due to abundant matrix contents in the sedimentary sequence from the Neogene. And finally, there are possibilities of trapping mainly associated with structural traps like the development of compressive tectonics.
- Thus, three exploratory plays are recommended: the first one in the southern region of the eastern structural zone, in which there can be structures in depth associated with the W-vergent imbricate fan; the second one in the western structural zone, where it is assumed that the broad and continuous structures may also be continuous in depth, reaching the Iró Formation; and finally, the

subthrust of the basement in the Western Cordillera Foothills, in which the Iró Formation is located below the high-angle faults of the basement.

- It is important to mention that given the geographical conditions of this project, the geological survey of the Seismic Program CHOCÓ – 2D 2005 was carried out based on punctual and relatively isolated outcrops along the 5 seismic lines, which does not provide a geological survey detailed enough to obtain typical sections of the units or approximate measures of their thickness.
- The Sierra Formation (in the ANH nomenclature) corresponds to a transition unit between the Iró and Istmina formations. In different segments it has a great lithological similarity with both units. This is the reason why it is suggested not to use this unit (avoiding at the same time homonymy issues with the Sierra Formation) described by other authors (Duque-Caro, 1990). The suggestion is to adopt the division defined by INGEOMINAS in which there is no description of a unit between the deep marine deposits of the Iró Formation (Formations Tadó or Salaqui by INGEOMINAS) and the continental to shallow marine deposits of the Istmina Formation (Uva Formation), where the Sierra Formation may correspond to an inferior segment of the Uva Formation.
- It is recommended to carry out an analysis of biostratigraphic datation to revalidate the information collected on the field, essentially among those units that have great lithologic similarity, for example the following formations: Sierra, Istmina, Conglomerados de la Mojarra, Condoto, and Munguidó, as well as Iró and Sierra formations.
- Similarly, the recommendation is to carry out detailed petrographic analyses for the description of each unit, with the support of geochemical analyses, to define the source areas and, therefore, to understand better the evolution of this basin, as well as the processes that affected its development.
- Given the geographical conditions of the project, most wells were drilled with water drillers; as a consequence, for the suggested geochemical analyses of the well samples, it has to be taken into account that bentonite and cydril were used as additives for the drilling process.

REFERENCES CITED IN THE ORIGINAL WORK

Barreo, D.; Laverde, F.; Ruiz, C. and Alfonso, C. (2006). Oblique collision and basis formation in western Colombia: The origin, evolution and petroleum potential of Cauca-Patía Basin. IX Simposio Bolivariano. Explotación petrolera en cuencas subandinas. Cartagena, Colombia.

Case, J.; Durán, L.; López, A. and Moore, W. (1971). Tectonic investigations in western Colombia and eastern Panama. Geological Society of America Bulletin. V. 82. Pp. 2685-2712.

Cossio, U. (2003). Geología de las planchas 202 Pilizá, 203 Istmina, 221 Pizarro y 222 Sipí. Departamento del Chocó. Escala 1:100000. Memoria explicativa. Instituto de investigación e información geocientífica, minero-ambiental y nuclear INGEOMINAS.

Duque-Caro, H. (1990). The Choco Bock in the northwestern corner of South America: Structural, tectono stratigraphic and paleographic implications. Journal of Southamerican Earth Sciences. Vol 3. No. 1. pp. 71-84.

Mera, R. and Piragua, A. (2001). Sección estratigráfica de la quebrada Suruco, análisis estructural de fracturas. Área del río San Juan, Chocó. Petrobras Internacional S.A. Asesorías Técnicas Geológicas Ltda.

Peña, J. H. (1996). Informe técnico anual (1995). Contrato de Asociación Chocó Central. Repsol Exploración Colombia ECOPETROL. Bogotá.

Rodríguez, E. (1990). Informe geológico: Área de la asociación Istmina. TEXAS PETROLEUM Co. Informe 2352. ECOPETROL. Bogotá.

Suárez, M. (1990). Estado actual del conocimiento geológico de la provincia del pacífico. ECOPETROL. Bogotá.

Zapata, G. (2001). Geología y geofísica de la plancha 204 Puerto Rico (escala 1: 100000). Instituto de investigación e información geocientífica, minero-ambiental y nuclear INGEOMINAS.

INVENTORY, COMPILATION, INTERPRETATION AND COMPREHENSIVE EVALUATION OF THE GEOLOGICAL, GEOPHYSICAL AND GEOCHEMICAL INFORMATION OF THE ATRATO AND SAN JUAN BASINS. ARC CHOCÓ, COLOMBIA[1]

UNIVERSIDAD EAFIT

www.eafit.edu.co

2007

SUMMARY

This first geological exploration assessment of the Atrato and San Juan basins is based on a systematic compilation of basic researches made by different hydrocarbons and minerals exploration companies since the 40s. The result of the region's new geological-physical analysis, which is the purpose of this study, clearly shows the existence of three sedimentary basins inside the Arco Choco. The dimensions of the prospective structures allow to be optimist concerning the size of important accumulations. The presence of oil seeps on the surface certifies the ability of the hydrocarbon to move on by finding suitable rocks and using them as transportation channels. The undiscovered resources based on the obtained geological and geochemical models, and according to the results of the calculated mass balance for the San Juan Basin are around 600 MBPE (P50) and 850 MBPE (P50) in the Atrato Basin. The next exploratory programs will find in this document the required basis and guidelines for an appropriate design at the level of the existing knowledge on these basins.

[1] Inventario, compilación, interpretación y evaluación integral de la información geológica, geofísica y geoquímica de la cuenca Atrato y Cuenca San Juan, Arco Chocó, Colombia. Universidad EAFIT. Noviembre, 2007.

OBJECTIVE

The inventory, compilation, interpretation and comprehensive evaluation of the geological, geophysical and geochemical information from the Chocó Basin, aim to improve the knowledge about the basin concerning the exploratory potential.

LOCATION

The geographical location of the Choco Basin is defined at the west by the dividing water line of the Serranía de Baudó mountains, at the east by the western side of the Western Cordillera, at the north by the political limit with the Republic of Panama, and at the south by the Pacific Ocean coast line (Figure 1). The Chocó Basin is geographically divided on the Atrato River Sub-Basin at north, and the San Juan River Sub-Basin at south, separated by the Istmina-Condoto High. The approximated surface area of each Sub-Basin is 25000 km^2 for the Atrato, and 10500 km^2 for the San Juan. From the geological point of view, and as a result from this study, the Atrato and San Juan basins are redefined as different exploratory basins.

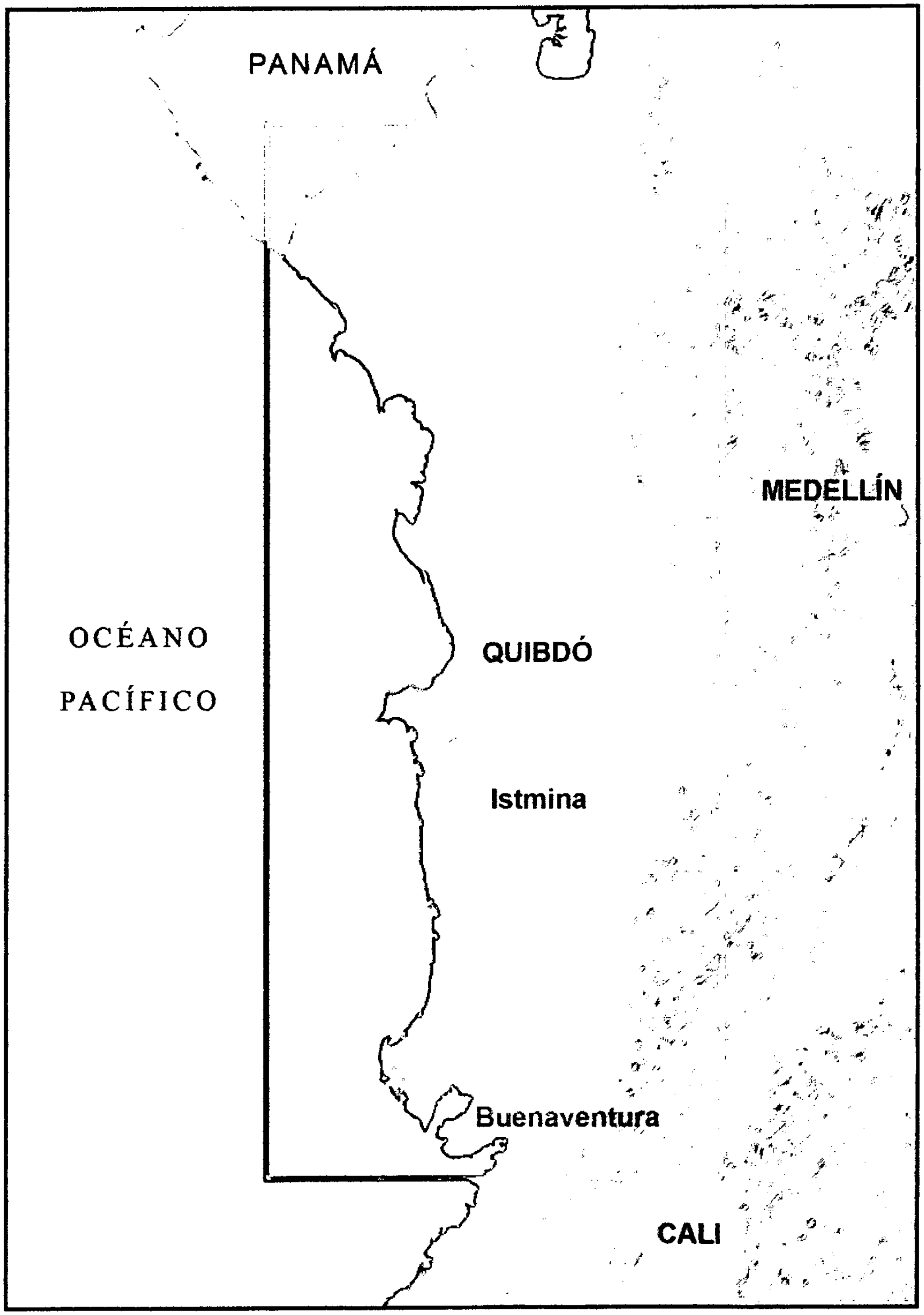


Figure 1. Location.

OVERVIEW AND RESULTS

GENERAL GEOLOGY

Geological situation

The Atrato, San Juan (and Urabá) basins are located in the Chocó-Panamá Arc (Figure 2). They are sedimentary deposits accumulated from the Paleogene over different cretaceous bases, mainly composed of oceanic crust remains, which contain island arc fragments. These oceanic terrains migrated since the end of the Cretaceous and successively collided or added to the continental border of the NW part of South America until closing the communication between the Pacific Ocean and the Caribbean Sea.

Stratigraphy and sedimentary facies

The so-called San Juan-Atrato Basin or Chocó Pacífico Basin is featured as a deposit in a range from marine to continental environments over an igneous-sedimentary complex. Nevertheless, the stratigraphic characteristics identified during the current revision and evaluation of the available data allows differentiating two different sedimentary basins: The Atrato and San Juan basins.

Atrato Basin

The sedimentary sequence is composed of six litho-stratigraphic units, which extend from at least the lower Eocene to the Pliocene.

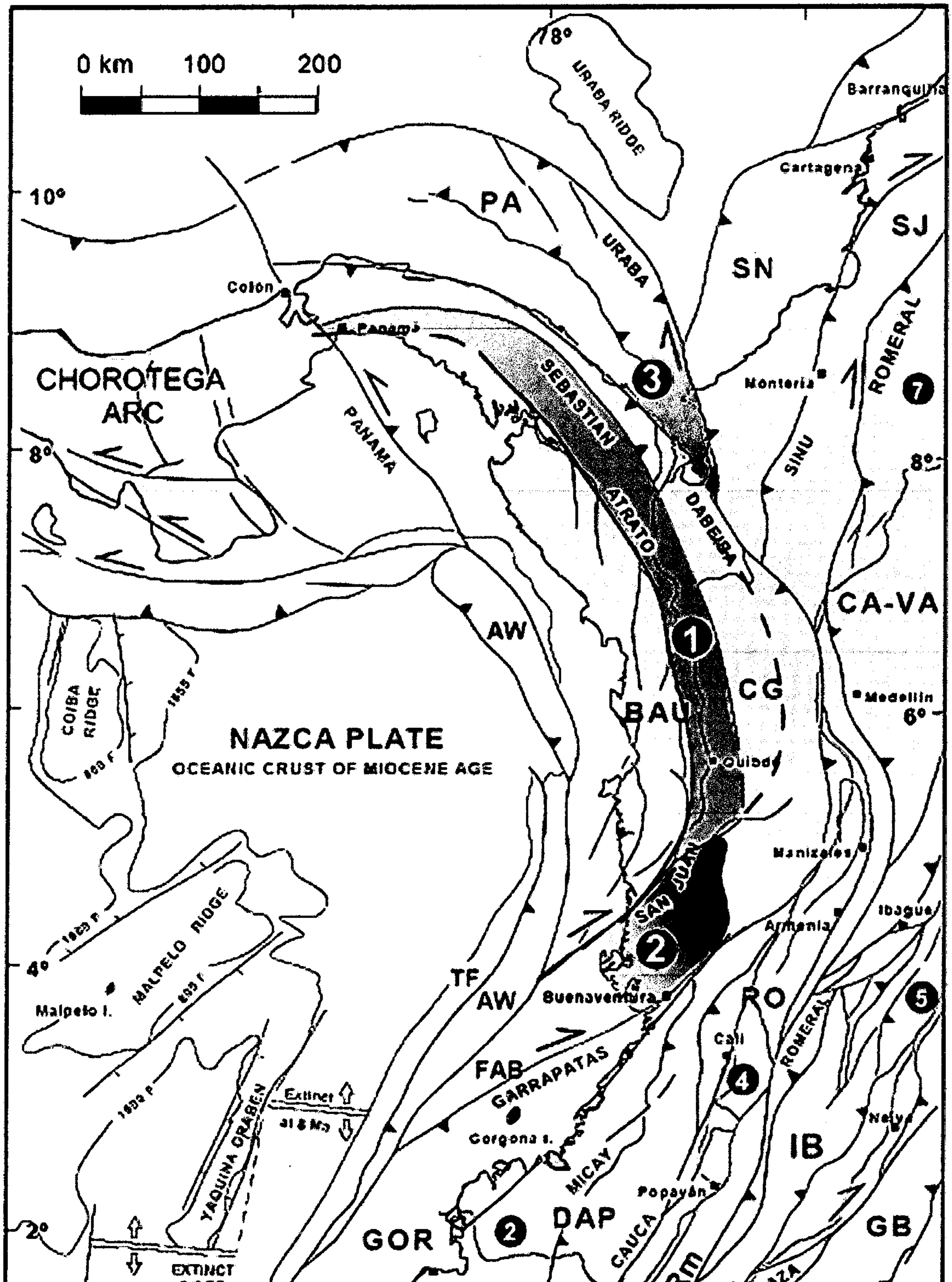


Figure 2. Geological location of the Atrato Basin (1), San Juan Basin (2) and Urabá Basin (3). Modified from Cediel et al. (2003).

The sedimentary sequence is composed by six litho-stratigraphic units, which extend at least from the lower Eocene to the Pliocene (Figure 3). Their temporary limits were fundamentally based on their fauna content (Haffer, 1967; Duque, 1991, Gradstein et al., 2004).

The Atrato Basin contains a dense sedimentary sequence of up to 10 km approximately, placed over an igneous-sedimentary base in predominantly marine environments, according to the reported fauna. However, it is remarkably influenced by transitional or continental environments during their latest geological development.

As for surface, the Uva, Napipí, Sierra and Quibdó formations are widely distributed over a great area of the basin's left border, and in lower proportion over its right border, at the Upper Atrato River Valley. On the other hand, the Clavo Formation is restricted to only an area of the basin's left border, and the Salaquí Formation, although it is located on the two borders, only appears in two sections.

The stratigraphic correlation of these units clearly shows the continuity degree and these relations in depth according to biostratigraphical interpretations on some wells. Five wells in total have been drilled from 1953 to 1983 during different hydrocarbon exploratory campaigns in the Atrato Basin. Likewise, the thickness variation is evidently in each one, indicating sedimentary processes controlled by differential tectonic activity. Generally speaking, the units tend to be thicker southwards.

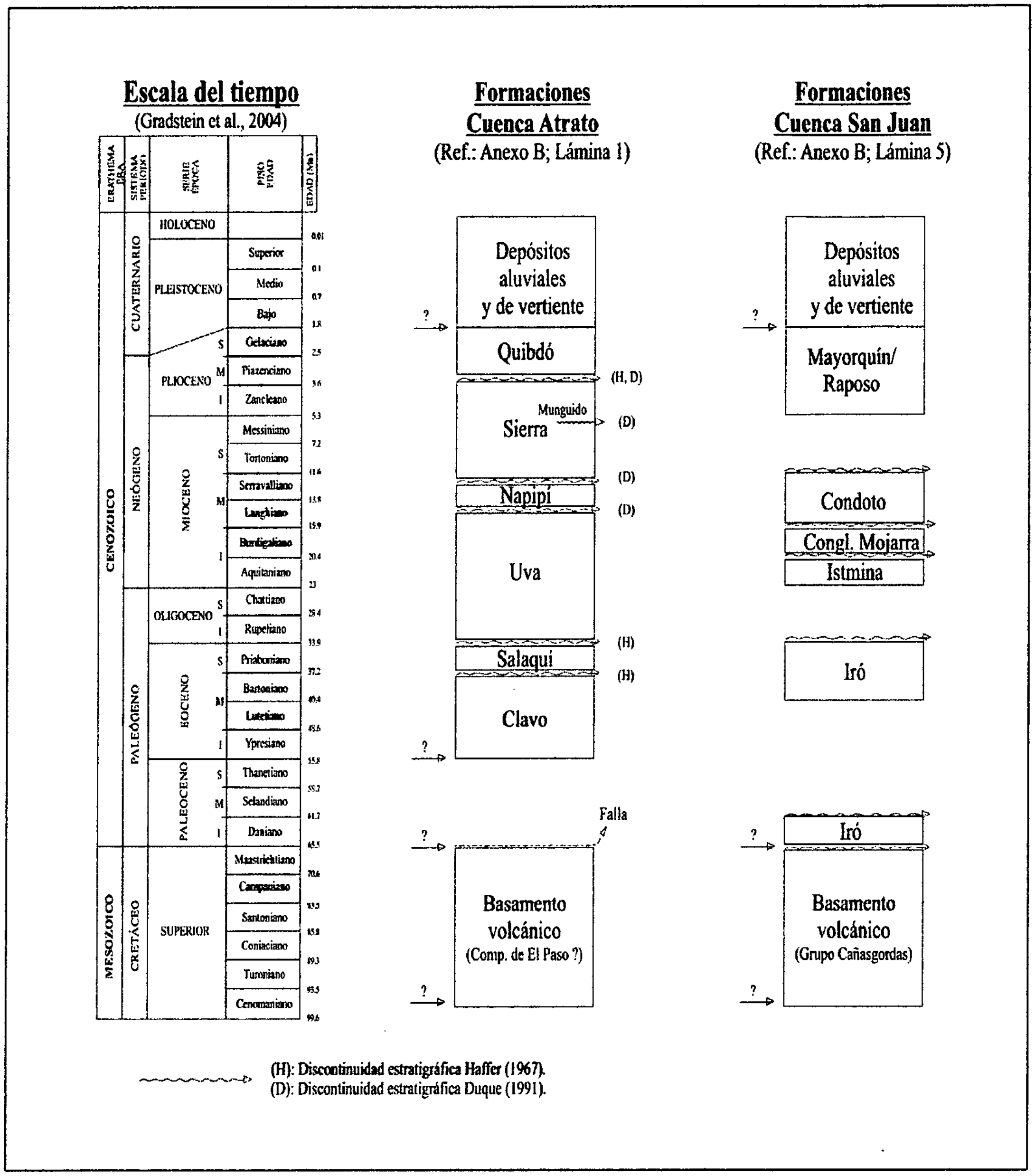


Figure 3. Defined Litho-stratigraphic units for the Atrato and San Juan basins.

San Juan Basin

The sedimentary sequence consists of five litho-stratigraphic units and extends from the Paleocene to the Pliocene. According to its fauna content, an important part of the sequence deposited itself in marine environments experiencing strong continental influence. The possible absence of rocks on the Paleocene-Eocene interval and the Oligocene-upper Miocene periods suggests (as evidenced at the Istmina-Condoto High) intensive erosion and long duration processes. As for surface, the Raposo and Mayorquín pliocenic formations cover a great part of the basin area. The Iró Formations and the Conglomerados de la Mojarra Formation appear only in the Condoto's High, while the Istmina and Condoto formations appear on different sectors of the basin.

The available data did not allow building stratigraphic correlation models as the ones made for the Atrato Basin. However, a facies interpretation derived from it, as defined from the seismic data. This interpretation suggests continuity of the lithological units defined at the Istmina-Condoto High, along most of the basin. Likewise, a thickness increase on the stratigraphic units is noted southwards.

STRUCTURAL GEOLOGY

Aeromagnetic and aerogravimetric interpretation

The characterization of a sedimentary basin includes, as well as the determination of its geometry, thickness and lithological composition, the knowledge on its base and the structures affecting it; this is the only way to understand its evolution. The geophysical modeling and characterization of the base at two different basins, the Atrato and the San Juan basins (formerly denominated Chocó Basin), was achieved through the use of aerogravimetric and aeromagnetic data.

The aeromagnetic and aerogravimetric data were provided by the National Hydrocarbon Agency (ANH) and by ECOPETROL, according to a previous request by the ANH. The data covers mainly the Atrato Basin. The campaign was carried out at an altitude of 1280 m and flight network of 7.5 km x 10 km. The data from ECOPETROL covers the San Juan Basin.

Bouger Gravimetric Anomaly (BGA), Gravimetric Basement, and Total Magnetic Intensity (TMI) maps are presented in Figures 4, 5 and 6 respectively. The modeling was carried out via profile elaboration. The profiles meet two characteristics: (1) they are perpendicular to the basin axis and (2) a part of them matches the trace of some seismic line.

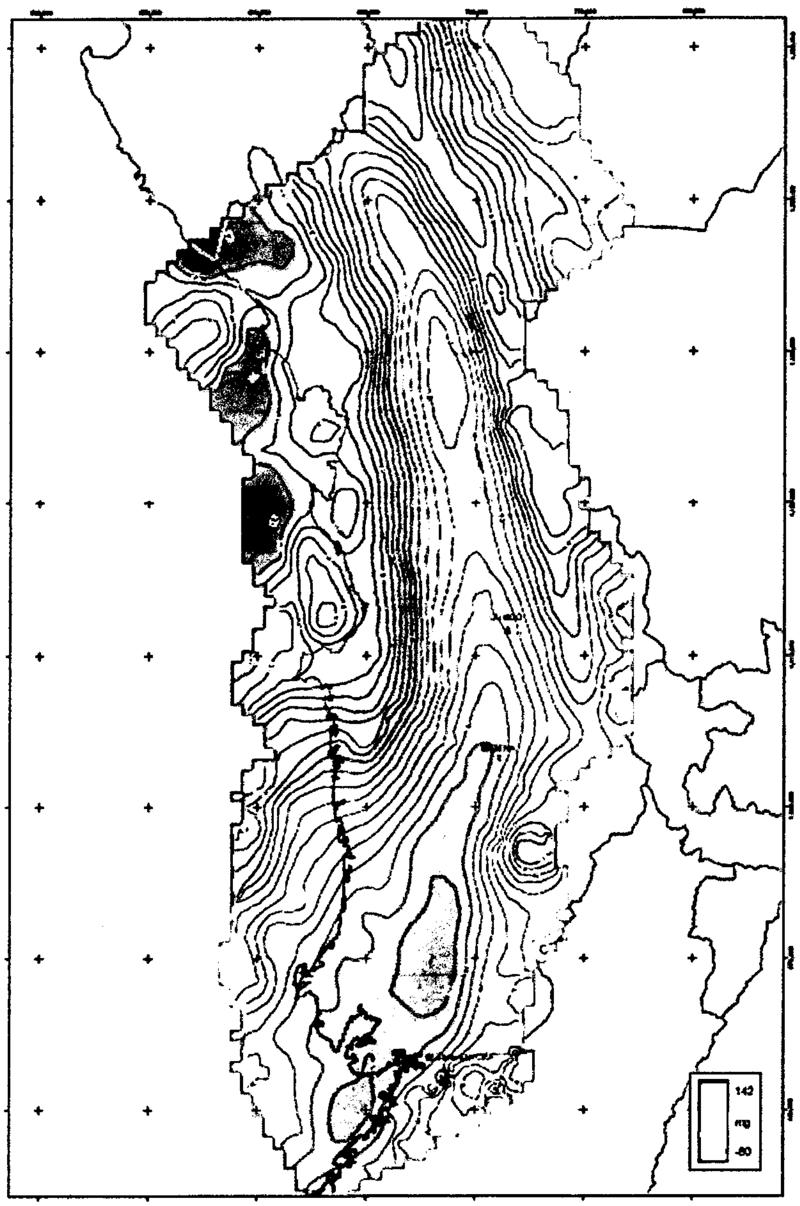


Figure 4. Bouger Gravimetric Anomaly map (BGA) (p=2.67).

Atrato Basin

This is an elongated basin with a N10W and asymmetric tendency. Its western side (W) shows lower slopes than the ones from the easter side (E). It moves on zig-zag and becomes wider southwards. It shows maximum depths of 10 km. On the BGA map it is defined by having the lowest anomaly values and on the TMI map it has relatively homogeneous characteristics at the central portion of the basin. Towards the basin sides the TMI values become more irregular due to the existence of faults and the contact with greater magnetic susceptibility bodies.

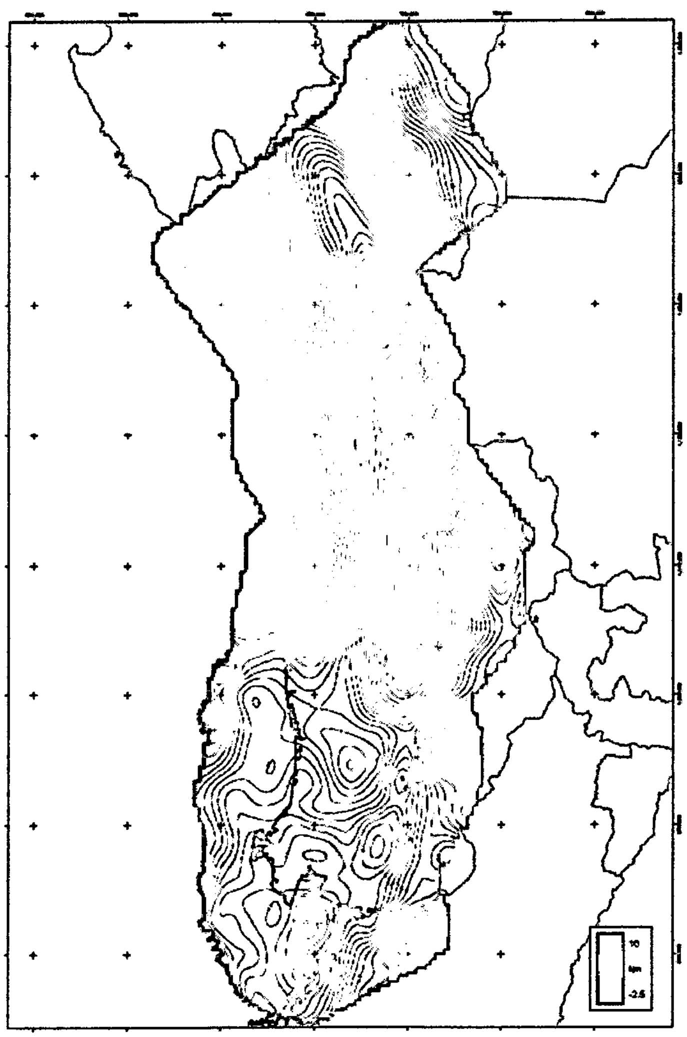


Figure 5. Basement map.

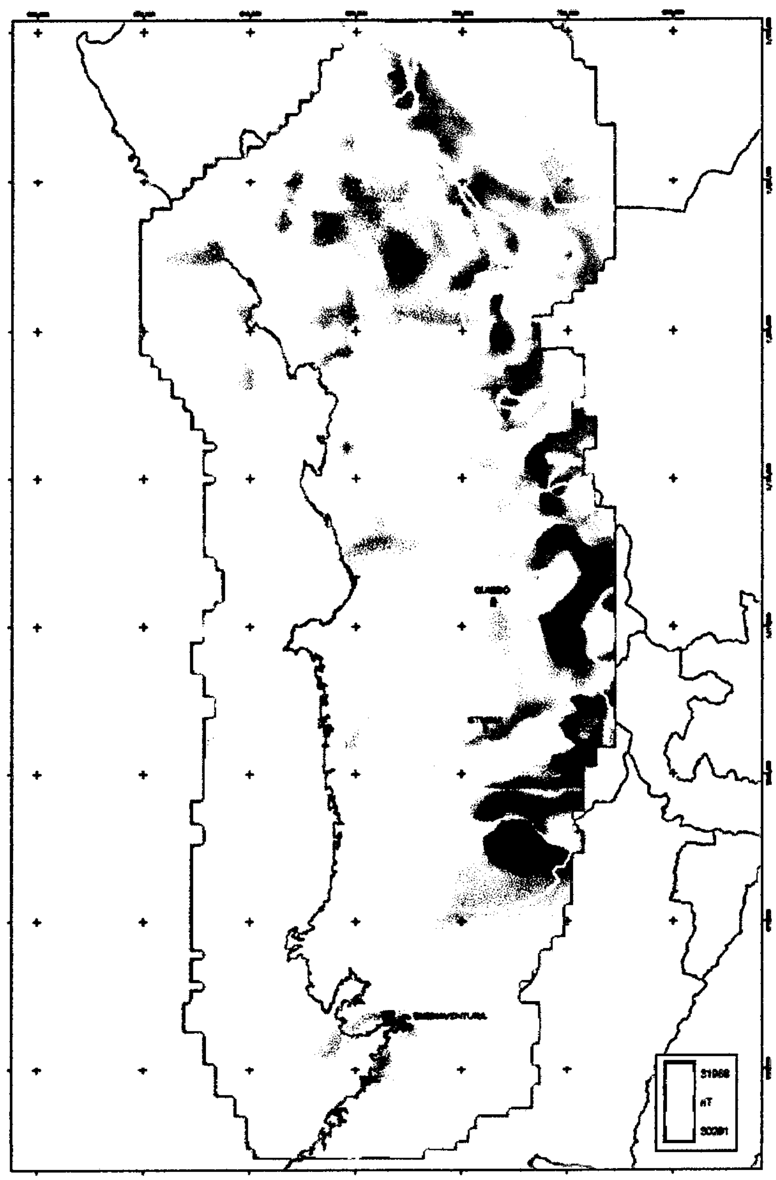


Figure 6. Total Magnetic Intensity map.

San Juan Basin

This basin is clearly separated from the Atrato Basin as shown on the Basement map. Its geometry is quite different from the Atrato Basin. It is limited by the San Juan Faults System at north, and the Garrapatas Faults System at south. On the TMI map, it has low values and at the offshore area near the San Juan River Delta, it presents a minor anomaly generated by sediments with magnetic susceptibility released to the ocean by the river. The strongest anomaly on the TMI is located at the north of the basin and corresponds to a mafic and an ultramafic bodies that set a control over the basin, strangulating it towards this direction.

Baudó Arc

The Baudó Arc is well delimited on the three modelled maps. With an elongated geometry, with north-south tendency, this body encloses the Atrato Basin at the west. The BGA map delivers the highest values on the area for this body, even higher than the ones found on the west border of the Western Cordillera, which has a much higher relief. The TMI map shows a Baudo arc faulted in different directions, a group of faults from east to west stands out.

Western side of the Western Cordillera

It borders at the east of the San Juan Basin, it is a well differenced body on the three generated maps. On this side, some bodies stand out such as the deformed Dabeiba Arc at north of the area, which divides the Atrato Basin from the Urabá Basin. At surface, according to the INGEOMINAS geological map, it is masked by Quaternary deposits (scale 1:100000) but the produced magnetic and gravimetric signal is rather clear.

STRUCTURAL EXPRESSION ON SURFACE

The faults and folds charted on surface are the result of limited field observations, registered in different reports, as well as a product of interpretation of aerial photographs; all this available data were compiled to a 1:500000 scale, reinterpreted and corrected through the study of a digital elevation model and radar images to produce a structural surface map.

Atrato Basin

The Atrato Basin is limited at the west by faults, which make the "Baudó Complex" to get into with contact various sedimentary units; some of these faults could correspond to discordant contacts. The general impression is that the whole system is constituted by a series of growth-faults from different ages.

Deformed area of the Istmina-Condo High

The Istmina-Condoto upper part structure is an assembly of faults with SW-NE direction and with different styles. The whole assembly creates a wide deformation area in which sedimentary and igneous rocks are associated. It is an extended shear zone, with a right lateral movement path. This movement is propagated inside the magmatic Mandé Arc, as well as in the fault system than compose the eastern side of the Atrato Basin.

The current San Juan River Delta as a geological model of the Cenozoic San Juan Basin

The approximated area of the current San Juan River Delta is a rectangle defined between latitudes 4° 20′ N and 3° 40′ N and longitudes 77° 20′ W and 77° 40′ W, south-center of the Pacific Coast of Colombia. It has an area of approximately 2000 km^2 that includes the continental shelf and slope between the actual San Juan Prodelta and the southern end of the Tortugas Gulf.

Based on the current available information, the San Juan Basin is understood within a Cenozoic deltaic model, which by analogy turns it into an exploratory goal. There are not only deltaic environmental conditions to generate hydrocarbons, but the occurrence of great mud diapirs is documented, which could generate the stratigraphic and structural traps, known today as "plays", prospects and production structures, on shore and off shore.

Structural sections

For the elaboration of sections in the present work, the interpretation of six seismic lines was used, with nomenclature according to the Seismic Atlas of Colombia (Cediel, et al. 1998). The "Kink" method for building folds (Mitra & Namson, 1991) was chosen for making the structural sections.

The conjugation of the faults' high angles, low falls, absence of folds associated to faults, and the simultaneous presence of normal and thrust faults leads to the conclusion that this is a regional tectonic pattern dominated by transcurrent movements.

GEOPHYSICAL INTERPRETATION

Petrophysical Evaluation

Objectives

To perform the petrophysical analysis in five wells drilled in the sedimentary Chocó Basin by different companies operating between 1953 and 1983, with the purpose of determining clay volumes, lithology, porosity and fluid saturation over the different potential reservoirs.

Results

Average values of petrophysical properties where obtained using the following differentiations:

VCL maximum 65%

Minimum Porosity 1%

Sw maximum 50%

The results are shown in Table 1.

Table 1. Petrophysical properties (average values).

Borehole	Top MD (ft)	Base MD (ft)	Total thickness (ft)	Net thickness (ft)	Ratio N/G	PHIE (%)	Sw (%)	Vcl (%)
Nécora-1	43	6490	6447	32	0.005	10.5	77.5	62.6
Pacurita-1	3957	8984	5028	106	0.021	15.4	81.0	46.5
Opogadó-1	94	11357	11263	395	0.035	12.0	90.4	58.6
Urodó-1	62	15002	14940	1154	0.077	7.8	99.1	34.6
Buchadó-1	2399	15539	13141	911	0.069	14.5	100	45.6

MD-average depth; PHIE-effective porosity; Sw-water saturation; Vcl-clay volume

The related unit on each well does not contain hydrocarbon saturated areas, and is not a producer on any of the analyzed wells.

Conclusions

Only the Nécora-1 and Pacurita-1 wells have recorded data that led to a quantitative interpretation of the data. In general, the drilled units have a high content of clay and do not contain a well developed oilfield; however, it is possible to identify small sandy packages with deposit quality, porosity from 8% to 15%, and water saturation greater than 80%. There have not been found commercial hydrocarbon deposits on the drilled wells, but there have been petroleum and gas signs during the drilling process.

SEISMIC EVALUATION

On the surface geology reinterpretation process carried out during this project, as well as on previous interpretations, it can be observed a sequence of faults with opposite character that crosses the arc with north-east, south-west direction, which are corroborated by the information found on the seismic surveys (Figure 7). These faults correspond to a *Wrench Assemblage* zone, as a result of the enclosure of the Baudó Arc.

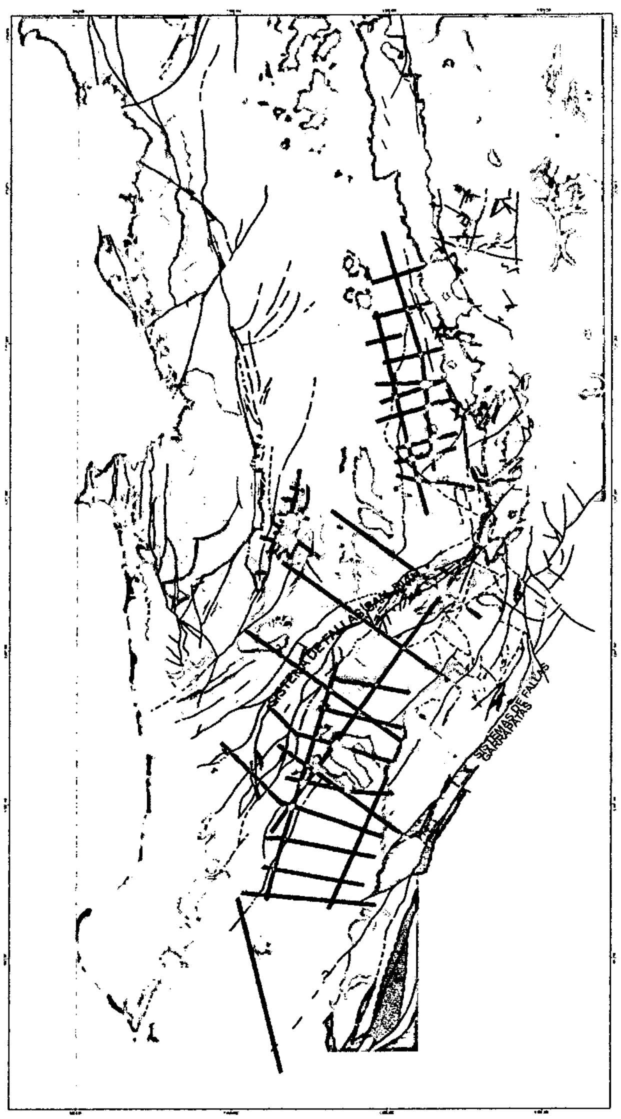


Figure 7. General view showing the relation between the location of existing seismic lines and the regional geological chart.

The seismic information is read and loaded to GEOGRAPHIX™, specialized software from LANDMARK.

The study was followed on three phases:

Interpretation of tectonic stratigraphic units

The interpretation of tectonic-stratigraphic sequences is based on the identification of characteristics from seismic data such as reflector ends, amplitude variations, continuity, frequency, geometry and interval rate, from which the surface drawing is made (horizons, non conformities) and faults, starting on the implementation of an interpretation methodology based on stratigraphic seismic modeling, which focused on defining the seismic sequences limits.

As a result, we have the interpretation and definition of settings, geometry, extension, continuity, and structure of the study area, as well as the time relation between the different tectonic and sedimentary events.

Subsoil cartography

The objective of this phase is to define the stratigraphic and structural characteristics of the study area from the observable seismic characteristics, relating them to sedimentary and tectonic events registered in this area.

Tectonic stratigraphic interpretation of the Atrato Basin

The stratigraphic interval concerning the Atrato Basin corresponds to tertiary sediments that are discordantly placed over a non-determined base. The defined units in the basin are described based on the information from the few wells drilled on it, and the available sources. The formation Clavo, Salaquí, Uva, Napipí, Sierra and Quibdó units are defined on this work.

Tectonic stratigraphic interpretation of the San Juan Basin

On the integrated evaluation of the San Juan Basin, there have been defined tertiary sediments, consisting of calcareous and siliciclastic marine sequences, discordantly placed over a non determined base.

The seismic characteristics found in this basin show important differences with those found in the Atrato Basin concerning thickness, disposition and geometry. The basin limits are determined at north and west by the Condoto "Paleohigh" (named on this work), at the east by the Western Cordillera and at south by the Pacific Ocean, following the course of the San Juan River.

There are 3 tectonic-stratigraphic sequences defined into this basin: Tectonic-stratigraphic unit 1 (Iró, Istmina formations), Tectonic-stratigraphic unit 2 (Conglomerados de la Mojarra, Condoto formations) and Tectonic-stratigraphic unit 3.

GEOCHEMICAL ANALYSIS

The presence of active sources in both San Juan and Atrato basins indicates the generation and migration of crude and the existence of at least two petrolific systems. With the purpose of evaluating this petrolific systems, a reinterpretation of all the available data was made, in order to characterize, from the geochemical point of view, the prospective source rocks, correlating them with the crude found on the sources and simulate the hydrocarbon generation and expulsion processes on the two basins.

San Juan Basin

The evaluation and characterization of the source rock was made through the analysis of quantity, quality and maturity parameters of the organic matter.

Thermal maturity

The maturity level for the entire section (Upper, Middle and Lower Iró units) presents an average T_{max} of 435°C, which describes it as immature, very close to entering the oil generation window.

Organic content

The upper Iró unit presents TOC values, which vary from 0.12 to 23.95% with an average of 7.55% that places it on the excellent range; the middle Iró unit presents a TOC average of 2.12% that places it on the good range and the lower Iró unit presents an average of 4.77% that places it on the excellent range.

Potential of Generation

The upper Iró Unit presents an average petrolific potential (S1+S2) of 39 mg Hc/g of rock, placing it as an excellent potential; the middle Iró Unit presents an average petrolific potential of 9 mg Hc/g of rock, placing it in a good potential and the lower Iró unit presents an average petrolific potential of 23 mg Hc/g of rock, placing it in an excellent potential. In general, relating the genetic potential (S1+S2) with the organic content percentage. The Iró Formation samples (upper, middle, lower) present a generating potential from favorable to excellent.

Conclusions for the San Juan Basin

The geochemical characteristics determined on this characterization indicate that some intervals from the Iró Formation present a high organic richness, and an excellent generating potential. It is relatively higher than the characteristics of hydrocarbon source formations located on the Middle Magdalena Valley (MMV) and the Upper Magdalena Valley (UMV).

The extracts and the less biodegraded crude from the source have a good correlation on its geochemical parameters, which suggest that more mature facies from the Iró Formation can be genetically related to hydrocarbon manifestations.

The interpretation of biological markers suggest that facies from the Iró Formation where deposited in a suboxic marine platform environment with carbonatic influence.

According to the model, the generating rocks reach the oil generation window at about 12000 feet.

The C interval located at the end of the Lower Iró Formation is the only one that expels hydrocarbons and its greatest volumes came out at the late Eocene, early Miocene and Pliocene.

Any generating interval that had been located under the C interval into the lower Iró Formation would have a transformation percentage of 100% and its expulsion would have been earlier. The transformation rates for the C interval are about 80%.

Atrato Basin

This basin does not count on recent quantifiable geochemical analysis data. In general, low thermal maturity is reported for the studied rocks.

Organic content

According to Robertson (1988), the organic matter content reported for the Buchadó-1 Well is low.

Generating potential

According to the limited evaluated information, the generating potential of the Clavo Formation is apparently poor.

Conclusions for the Atrato Basin

The oil and gas samples reported at Buchadó Well, added to the found sources, are evidence of hydrocarbon generation in the basin, which should finally correspond to a undiscovered deposit of facies (generating interval) with good generating characteristics that have been not geochemically characterized.

According to the proposed hypothetical expulsion and generation model, any interval with good generating characteristics located under 11000 feet would have expelled hydrocarbons.

The generating interval for Clavo starts generation on the middle Eocene, reaching a transformation percentage of 100%.

The main generation peaks for this generating interval would be concentrated between the late Miocene and the Pliocene.

PETROLEUM GEOLOGY

The structures found on the Atrato and San Juan basins are recently created. The hydrocarbon generation possibilities, according to this study, are placed before the generation of the structure. The dimensions of interesting structures allow us to be optimistic regarding the dimensions of the possible accumulations.

The presence of oil *shows* at surface certifies the possibility of the hydrocarbon to move on by finding suitable rocks and using them as transportation channels. Although an appropriate logistical infrastructure for starting exploration campaigns does not exist, its strategic location towards the Pacific Basin, and its proximity to the port of Buenaventura are valuable elements for promoting it as a future basin.

Several identified traps can be listed:

Atrato Basin

Stratigraphic traps, into the Salaquí and Uva formations, to the east side of the basin.

Structural traps, associated to anticlines originated by the inverse fault on the basin's western side.

Structural traps, consisting on folds associated to diapirs action events, on the basin's western side.

San Juan Basin

Combined traps (structural and stratigraphic) associated to the great progradation reported south of the basin.

Stratigraphic traps, associated to the stacked calcareous bodies that in general, when exposed, have a secondary porosity, therefore, a great possibility of hydrocarbons accumulation.

Structural traps of anticlinal folds associated to inverse faults on the basin's margins.

Source Rocks

The presence of source rocks in San Juan and Atrato basins is based on the geochemical characterization of the Iró Formation, near the Istmina-Condoto High. According to these data, this unit presents immature rock intervals with good to excellent generating potential. These intervals present high content of organic matter and kerogen type II with high content of hydrogen. If the organic facies on these units keep the direction to the basin's deepest places, the characteristics of source rock would be one of the most attractive subjects on the exploration of these basins. Moreover, it is possible that in poorly studied units as the Salaquí Formation, additional generating intervals might be found.

Generation and Migration

Based on the hydrocarbon generation modeling (1D), it is possible to state that the lower part of the Iró Formation in the San Juan Basin, and its chrono-stratigraphic equivalent of the Clavo Formation in the Atrato Basin, reached important hydrocarbon generation and expulsion processes during the late Miocene-Pliocene. The hydrocarbon volumes expelled by these units will generate interesting expectations regarding the quantity of undiscovered resources, in case of a trap existence.

<u>Undiscovered Resources</u>

Based on the geological and geochemical model, a mass balance was made for the two basins. According to this balance results, there are expectations of undiscovered resources of about 600 MBPE (P50) at San Juan Basin and 850 MBPE (P50) at Atrato Basin.

REFERENCES CITED IN THE ORIGINAL WORK

Cediel, F., Barrero, D., and C. Cáceres (1998). Seismic Atlas of Colombia: Seismic expression of structural styles in the basins of Colombia. Robertson Research Internat., U.K., Geotec Ltda. Vol. pp. 1-6.

Cediel, F., Shaw R.P., and C. Cáceres (2003). Tectonic assembly of the Northern Andean Block, in Bartolini, C., Buffer, R.T. and Blickwede, J., eds., The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics: AAPG Memoir 79, pp. 815-848.

Duque-Caro, H. (1991). Contributions to the geology of the Pacific and Caribbean coastal areas of northwestern Colombia and South America: Princeton University, PhD. thesis. 132 p.

Gradstein, F.M., Ogg, J.G., and Smith, A.G., Agterberg, F.P., Bleeker, W., Cooper, R.A., Davydov, V., Gibbard, P., Hinnov, L.A., House, M.R., Lourens, L., Luterbacher, H.P., McArthur, J., Melchin, M.J., Robb, L.J., Shergold, J., Villeneuve, M., Wardlaw, B.R., Ali, J., Brinkhuis, H., Hilgen, F.J., Hooker, J., Howarth, R.J., Knoll, A.H., Laskar, J., Monechi, S., Plumb, K.A., Powell, J., Raffi, I., Röhl, U., Sadler, P., Sanfilippo, A., Schmitz, B., Shackleton, N.J., Shields, G.A., Strauss, H., Van Dam, J., van Kolfschoten, T., Veizer, J., and Wilson, D. (2004). A Geologic Time Scale 2004. Cambridge University Press, 589 p.

Haffer, J. (1967). Geologic compilation map Northwestern Colombia. Colombian Petroleum Company, Escala 1:500.000.

Mitra, S. & Namson, J. (1991). Balanced Cross Sections in Hydrocarbons exploration and production, an AAPG short course.

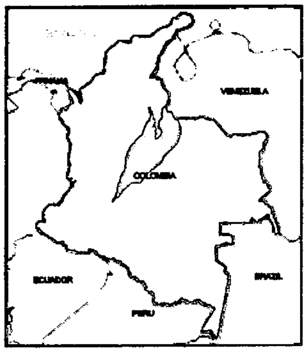
Robertson Research (1988). The biostratigraphic, paleoenvironments and petroleum geochemistry of the Buchadó-1, Tambora-1 and Sandí-1 wells, Pacific coastal region of Colombia. Report No. 3792/Ib for ECOPETROL. Bogotá. 104 p.

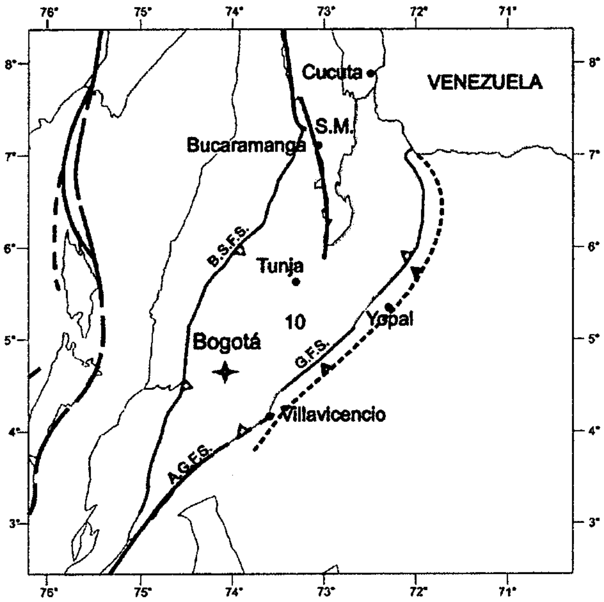
4. EASTERN CORDILLERA BASIN

The Eastern Cordillera Basin is composed by rocks formed in an inverted Late Triassic Rift System that resulted from the break-up of Pangea, and was filled by Mesozoic marine and Cenozoic continental sediments. By the Early Paleogene Period a dextral transpressional deformation triggered faulting and folding, and played a fundamental role in the structural inversion of this basin.

As a consequence of its origin and structural development, the nowadays limits of the basin are very irregular and difficult to describe. In a general way, east and west limits are well developed en-echelon faults that thrust-over the adjacent basins, the eastern limit is known as the Guaicáramo Fault System; the western limit as the Bituima - La Salina Fault Systems. The southeast boundary is the Algeciras-Garzón dextral strike-slip Fault System, and the northern limit the igneous and metamorphic rocks of the Santander Massif (Figure 1).

EASTERN CORDILLERA BASIN
LOCATION AND BOUNDARIES





BOUNDARIES

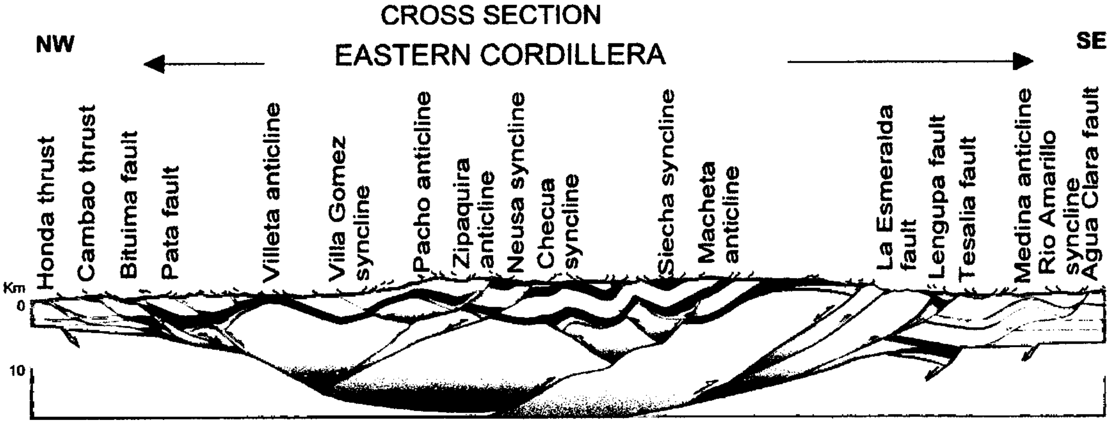
North: Igneous and metamorphic rocks from the Santander massif (S.M.)

East: Guaicaramo Fault System (G.F.S)

South: Algeciras-Garzón Fault System (A.G.F.S.)

West: Bituima and La Salina Fault System (B.S.F.S.)

CROSS SECTION
EASTERN CORDILLERA



Take from Restrepo-Pace, P. et al., 1995

- Late Miocene-Recent
- Late Oligocene-Early Miocene
- Eocene-Early Oligocene
- Paleocene
- Cretaceous: Albian - Maastrichtian
- Cretaceous: Berriasian - Aptian
- evaporites
- Precambrian-Paleozoic

Figure 1. Eastern Cordillera Basin.

GEOLOGICAL CARTOGRAPHY EASTERN CORDILLERA BASIN, SOÁPAGA SECTOR[1]

Geoestudios Ltda.

www.geoestudioscolombia.com

2006

SUMMARY

The study area is geolocally located at the far east of the Floresta Massif. Outcropping rocks, whose ages fluctuate between the Paleozoic (Pre-Cambric) and the Cenozoic (Neogaean) can be found. The rocks from the Paleozoic and basal part of the Mesozoic (Jurassic Triassic), form the Floresta Massif; the ones from the mid and upper Mesozoic and the ones from the Cenozoic (Cretaceous and Tertiary), constitute the rocks, which surround the Massif containing outcrops to the south, east and west. The study area almost entirely corresponds to the 172 plane of Paz del Río (INGEOMINAS PLANE No. 172), and, for this reason, its stratigraphic nomenclature has been kept in this work. Nevertheless, it has to be pointed out that INGEOMINAS introduces in the Paz del Río area a mixture of the nomenclatures from the Sabana de Bogotá, from the Sogamoso-Duitama regions, etc.

Rocks from the Paleozoic, present within the Floresta Massif itself, are represented by metamorphites grouped in schists and filicites, which have undergone regional metamorphism and small outcropping of orthogneiss, as the most ancients rock in the area, and by intrusive rocks, which constitute Paleozoic stocks and more recent one, possibly Jurassic Tertiary (Otengá Stock). Inside the same Paleozoic, there are rocks from the Tibet, Floresta and Cuche formations.

---

[1] Cartografía geológica Cuenca Cordillera Oriental-Sector Soápaga. Geoestudios Ltda. July, 2006.

Rocks from the basal part of the Mesozoic (Triassic-Jurassic) are constituted by the Girón Formation, and by small outcrops from the La Rusia Formation.

The rocks from the Cretaceous outcrop west to the Massif in discontinued strips cut by Quaternary deposits, and to the east of the same massif in three elongated fringes: the first one, west to the regional Soápaga Fault, between this one and the Massif itself; the second one, making part of a narrow anticlinal structure (San Antonio Anticline); and the third one, towards the north-east edge of study area; likewise, at the central part of the La Chapa Anticline. The formations are: Tibasosa, Une, Chipaque, Plaeners, Los Pinos, Arenisca Tierna (Soft Sandstone), and Guaduas (Tertiary -Cretaceous Transition).

Tertiary rocks are constituted by the Arenisca de Socha, Arcillas de Socha, Picacho, and Concentración formations, which outcrop to the east of the Massif, and present themselves folded and faulted, constituting a very important part of this study.

Quaternary deposits are important at the western edge of the Massif, occupying extensive areas at the Santa Rosa de Viterbo-Cerinza-Belén Sector, and the road Belén-Paz del Río, which is at the farthest north-west edge on the rise towards Rusia Moor, where glacier and glacier fluvial deposits can be seen. On the eastern edge of the Massif colluvial deposits from great blocks take priority, and they occupy great areas in the Tasco-Paz del Río Sector and southwest from this latter locality.

The following rocks were studied using geological and structural control transects: rocks from the Paleozoic, igneous, metamorphic and sedimentary; rocks from the Triassic-Jurassic, igneous, and sedimentary rocks from the lowest Cretaceous (Tibasosa Formation), and from the upper Tertiary (Concentración Formation). The others (formations from the lower and upper Cretaceous and Tertiary) were studied through detailed stratigraphic surveys. This activity allowed to obtain a geological map including the litho-stratigraphic units, the quaternary deposits and the geologic structures. Additionally, five geologic cuts were done.

On the block, there can be clearly differentiated two tectonically different provinces limited by great high angle inverse faults generated from tectonic inversion events occurred during the Late Jurassic and Early Cretaceous. Each one of these provinces has a characteristic stile of deformation; the first province corresponds to Floresta Massif having a thick scaling tectonic, and the second one, is a folded cover made up by the Cretaceous and Tertiary sequence in the overlying block of the Soápaga Fault, which shows a thin-scaling tectonics represented by a series of inverse faults having ESE vergence, and directional faults with NE - SW course.

Ten stratigraphic columns (1:200 scale) were described and interpreted, which represent Cretaceous sediments from the Une, Chipaque, Plaeners, Los Pinos, Tierna, and Guaduas formations, as well as rocks from the Paleogean belonging to the Arenisca de Socha, Arcillas de Socha and Picacho formations. Additionally, measurements of radiation of totalGamma Rays (U+Th+K) were made.

The rock sampling was carried out during the geologic cartography (132 samples), during the stratigraphic columns survey (551 samples), and gathering seepage samples (from 16 proposed ones, only seven were found). Nine new sites with seepage and oil impregnation in rocks from the Picacho Formation were found.

LOCATION

The study area corresponding to the Eastern Cordillera-Soápaga Sector is located in the Boyacá Department, north of Sogamoso City, approximately 190 km NW from Bogotá. It corresponds to a polygon, which covers 678 km^2 (Figure 1).

Geologically, the area to be studied and mapped, is found at the central part of the Eastern Cordillera, being located at the meridional branch of the arc dominated by the Cocuy Massif; inside of it, part of the Floresta Massif is found. Cretaceous and Tertiary sedimentary sequence strip belonging to the area known as Pisba High can be found. The zone is limited to the west by Onzaga-Mogotes Massif, to the north by this latter one and part of the Santander Massif, and to the east by the Nevado del Cocuy Massif.

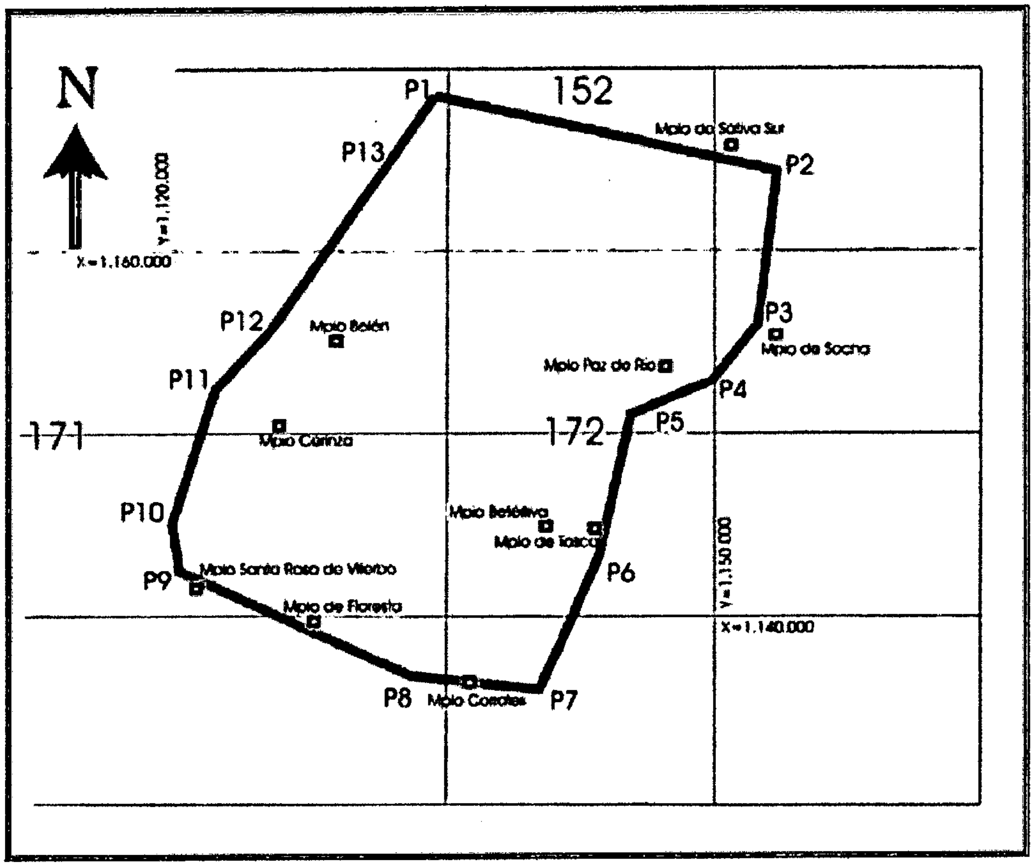


Figure 1. Location of the Soápaga Sector. Bogotá Datum.

METHODOLOGY

Initial Office Stage

At this stage, the geoscientific and cartographic information about the area of interest was compiled, analyzed and evaluated. Also a photogeological and remote sensors interpretation was carried out; this activity was helpful for the acquisition and interpretation of aerial photographs at an adequate scale, and it was complemented with interpretation of radar and satellite images.

Field Verification Stage

This stage is mainly made up of three work fronts; the first one, corresponds to geological cartography of the area; the second one, to the realization of stratigraphic columns surveys and their respective sampling; and the last one, to the gathering of seepage samples.

Geological Cartography

A total of 33 geological transects were carried out, and 8 structural transects along the roadways, roads, rivers and streams (Table 1).

Table 1. Length of geological and structural transects.

Type of Transect	TOTAL (km)
Geological	219.5
Structural	59.5
TOTAL	279

Along with the acquisition of data within the realization of the various types of transects, gathering of rock samples at each outcropping was carried out.

Stratigraphic Columns Survey, Rock Sampling, and Gamma Ray Readings

The lithostratigraphic sections survey of the units, which make up the Cretaceous and Tertiary sequence east of the Floresta Massif detailed to scale 1:200 was carried out, with the exception of the Tibasosa at the base of the Cretaceous and Concentración at the top of the Tertiary formations. In this activity 2557.90 m of stratigraphic column of Cretaceous sediments and rocks from the paleogean, were described and interpreted.

Parallel to the description of the columns, a systematic rock sampling, in order to characterize the outcropping lithologic units, was carried out. These samples were collected, packed and marked according to proposed guidelines. At this stage, a total of 551 rock samples were obtained.

The readings of Total Gamma Ray (U+Th+K) were carried out every 30 cm, three measurements being collected at each point.

Table 2. Total lenght of stratigraphic columns.

FORMATION	ROCK	COVERED	TOTAL
Concentración	13.30	0.00	13.30
Picacho	210.40	126.60	337.00
Arcillas de Socha	281.60	58.70	340.30
Areniscas de Socha	275.45	61.95	337.40
Guaduas	371.70	128.60	500.30
Arenisca Tierna	94.60	14.10	108.70
Los Pinos	168.05	0.00	168.05
Plaeners	183.35	7.00	190.35
Chipaque	247.10	54.40	301.50
Une	205.80	47.70	253.50
Tibasosa	7.50	0.00	7.50
TOTAL	**2058.85**	**499.05**	**2557.90**

Table 3. Number and purpose of samples gathered in the stratigraphic survey.

FORMATION	NUMBER OF SAMPLES		
	Petrography/ Petrophisics	**Biostratigraphic/Geochemical**	**TOTAL**
Concentración	1	2	3
Picacho	39	12	51
Arcillas de Socha	31	21	52
Arenisca de Socha	73	9	82
Guaduas	5	62	67
Arenisca Tierna	20	9	29
Los Pinos	39	23	62
Plaeners	23	25	48
Chipaque	0	88	88
Une	47	18	65
Tibasosa	2	2	4
TOTAL			**551**

Seepages Sampling

According to the design it was necessary to gather samples of oil from 15 seeps of the 16 proposed. All localities issued were visited (see an example in Figure 2). The non-existence of hydrocarbon, whether in liquid form or as impregnation in some of them, came up.

Table 4. Report on seepage samples gathered.

TYPE	QUANTITY
FLUID	8
IMPREGNATED ROCK	17
TOTAL	**25**

Figure 2. Station: JU266. Picture: JU266A. TYPE: Outcropping. File: JU. Azimuth: 190°. Description: Outcropping from the Picacho Formation with impregnation and seepage of hydrocarbon. Samples of fluid and rock impregnation: JU266A-JU266. Cerro Culatas Locality. Coordinates: N= 1.133.554, E = 1.136.371, Bogotá origin.

RESULTS AND CONCLUSIONS

Stratigraphy

Metamorphic, igneous and sedimentary rocks outcrop in the study area. The first ones, take part of the central core of the Floresta Massif and constitute the most ancient rocks of the zone. Bodies of important extension and some intrusive igneous rock stocks are located inside the same Massif. Sedimentary rocks, whose ages are between the Paleozoic and the Cenozoic ages make up part of the Massif, being the most ancient from Paleozoic-Jurassic and Triassic ages, or that form the rocks, which surround it at the west, as well as at the east. These latter ones are rocks from the Cretaceous and Tertiary and constitute the fundamental objective of this work.

For the description of the stratigraphic units, the outcropping rocks were divided into two characteristic groups of the Floresta Massif. One, represented by metamorphic, intrusive igneous, and pre-Cretaceous sedimentary rocks; and the other, by Tertiary - Cretaceous rocks, which surround the Massif.

Description of the rocks from the first group was based on the information gathered from the cartographic and structural transects carried out in field works, complemented with secondary information. The description of the second group (rocks from the Cretaceous and Tertiary periods) was basically made using detailed lithostratigraphic sections, except for the base of the Cretaceous (Tibasosa Formation), and the top of the Tertiary (Concentración Formation), for whose description data gathered from the programmed transects were used, as well as the ones coming from complementary trasses defined during the execution of field works. Characterization of the various units is made according to the type of rock, from the most ancient to the most recent ones. Figure 3 shows the stratigraphic generalized column of the work area.

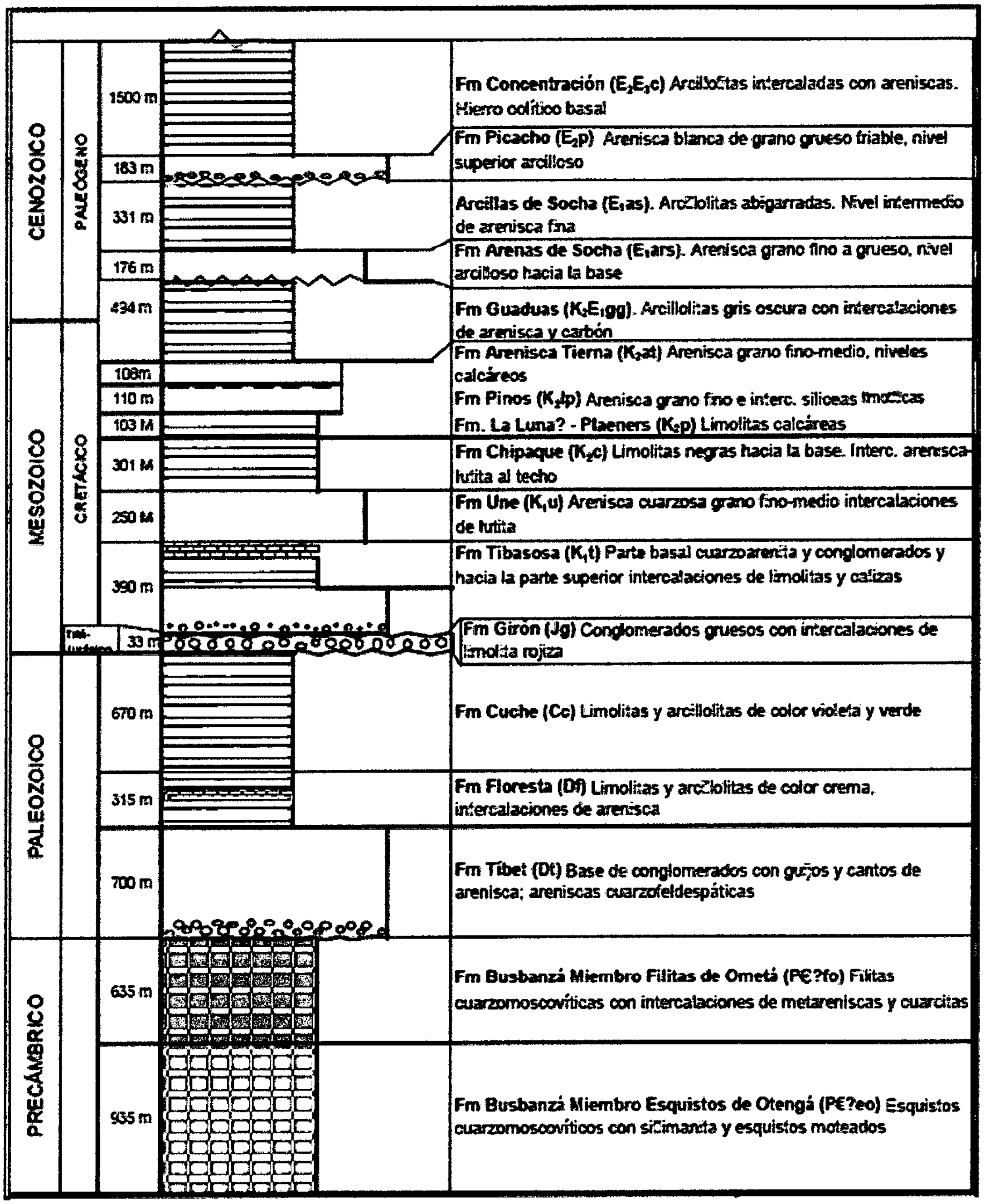


Figure 3. Generalized Stratigraphic Column of the Area.

Methamorphic Rocks

Field works allowed, at the first place, to differentiate two units of regional metamorphism. The first unit corresponds to filicites and schists from Busbanzá and Gneiss from Buntia, and the second is associated with dynamic metamorphism constituted by brecciated igneous rocks and some metasediments, which have been named Cataclastites from Soápaga.

Intrusive Igneous Rocks

Three important bodies are distinguished in the area: Monzonite-Quartz from Santa Rosita, located in the northwestern part and on the western edge of the Floresta Massif; the Stock of Otengá, which outcrops east of homonymous Police Inspection; and the lesser extension one, the Chuscales Stock, which appears west of Otengá, in the high parts of the Aguachica and Los Puentes streams. The latter two igneous bodies are located in the eastern part of the Floresta Massif.

Sedimentary Rocks

For description of these rocks, two groups are taken into consideration: The first one is constituted by formations linked to the Floresta Massif, from the Paleozoic (Devonian) up to the Lower Mesozoic (Jurassic- Triassic), involving Tibet, Floresta and Cuche formations from the same Floresta Massif, and the La Rusia and Girón formations, which surround the Massif. The second group would be formed by sedimentary rocks from Cretaceous and Tertiary, which outcrop on the western and eastern edges of the Massif inside the work area.

Petroleum Geology

The evaluations given on the oil geology are based only on field observations, study of the facies of the Cretaceous-Tertiary formations of the eastern sector of the Floresta Massif, and structural interpretation. Some aspects of generation or trapping of hydrocarbons are taken from later works done in the area.

Source Rock

As well as the rocks that generate hydrocarbons in the area, the muddy Cretaceous rocks, which show important contents of organic matter are taken into consideration. Examples include these ones, in the Tibasosa and Chipaque formations, considered from the Lower Cretaceous, and Plaeners and Los Pinos from Higher Cretaceous.

Reservoir Rock

Within this category, the sandstones from the Cretaceous formations are considered such as: Une, upper part of Los Pinos and Arenisca Tierna, and the Tertiary from the Areniscas de Soacha and Picacho formations.

Seal Rock

The following are considered as seal rocks: the arcillites, silstones and lodolites from the Chipaque formations, that superpose the sandstones from the Une Formation, the arcillites from Guaduas superposed to the Arenisca Tierna Formation, and the Arcillas de Soacha that superpose the Areniscas de Socha. Important leyers of arcillites from the Concentración Formation could constitute the seal for the sandstones from the Picacho Formation.

Traps

In the area, the traps would be linked to folded and faulted structures. These structures are generated by the first stage of deformation, and later on, are affected by various deformation events. Despite the great tectonism reflected in the study area, an important trapping is not inferred because the composing structures and units, and mainly the reservoir and seal formations, are exposed.

Structural Geology

At a general structural location of the area (Figure 4), there can be appreciated, as most outstanding characteristic, a preferential orientation of the arch shaped structures having SW-NE direction in the south sector, N-S in the central sector, and SE-NW in the far north, containing ancient rigid longitudinal bodies (Onzaga-Mogotes and Floresta massifs) in the central sector of the area, affected by faults of inverse type, which raise this base with respect to Cretaceous and Tertiary sedimentary cover that surrounds it.

Great part of the study area is constituted by rocks from the Floresta Massif, limited by faults of inverse type; these structures are linked to the recent raise of the Eastern Cordillera during the Andean Orogeny through reactivity with variation towards the displacement of the blocks (tectonic inversion); to the west, the Boyacá Fault limits it from the Onzaga-Mogotes Massif, and to the east the Soápaga Fault separates it from a folded pleaded cover composed of a Cretaceous and Tertiary series.

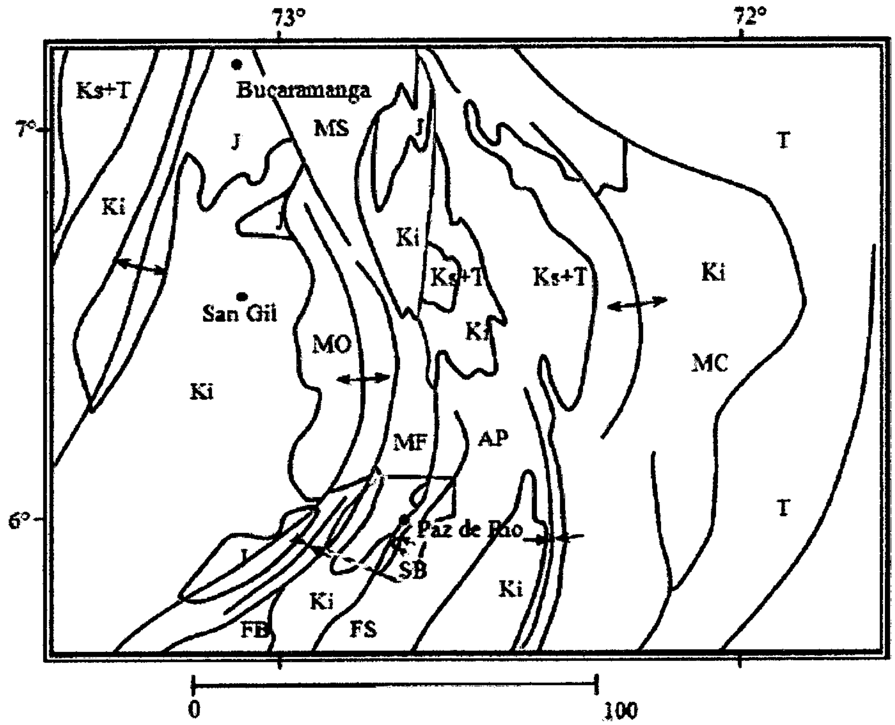


Figure 4. Structural location of the study area. MS: Santander Massif, MO: Onzaga-Mogotes Massif, MF: Floresta Massif, MC: Nevado del Cocuy Massif, AP: Pisba High, FB: Boyacá Fault, FS: Soápaga Fault, and SB: Beteitiva Syncline.

In general considerations, two tectonically different provinces can be clearly seen on the geological and structural maps and in the structural sections; each one of them has a characteristic deformation style. They are the following:

- Floresta Massif zone with a thick tectonic scaling in the hanging block of the Soápaga Fault, which mainly involves Pre-Devonian to Cretaceous rocks.
- Folded Cover – shows tectonic of thin scaling represented by a series of inverse faults having ESE vergence, and directional faults with NE-SW course, which only displace the series of Cretaceous and Tertiary rocks in the reclining block of the Soápaga Fault.

REFERENTES CITED IN THE ORIGINAL WORK

Alzate, D. J. C. & Bueno, V. M. (1994). Análisis Estratigráfico Secuencial de las Rocas Cretácicas de la Parte Oriental del Departamento de Boyacá, Municipios de Sogamoso, Belencito y Aquitania.

Cediel, F. (1969). Geología del Macizo de Floresta. I CongresoCol. Geol. Mem. pp. 17-29.

Colleta, B.; Hebrard, F.; Letouzey, J.; Werner, P. & Rudkiewicz, J. (1990). Tectonic Style and Crustal Structure of the Eastern Cordillera (Colombia) from a Balanced Cross Section. In: Letouzey, J. (ed), Petroleum and Tectonics in Mobile Belts, Ed. Technips, Paris. pp. 81-100.

Cooper, M. A. et al. (1995). Basin Development and Tectonic History of the Llanos Basin, Eastern Cordillera, and the Middle Magdalena Valley, Colombia. Bulletin of the American Association of Petroleum Geologist, v. 79, pp. 1421-1443.

Dengo, C. A. & Covey, M. C. (1993). Structure of the Eastern Cordillera of Colombia: Implications for trap Styles and Regional Tectonics. Bulletin of the American Association of Petroleum Geologist, v. 77, pp. 1315-1337.

Guatame, A. & Lara, G. H. (1995). Análisis Geoquímico de las Formaciones Prealbianas Fómeque y Tibasosa en un área al Norte de Tunja entre los municipios de Pesca, Nobsa, Santa Rosa de Viterbo, Belén y Betéitiva. Departamento de Geociencias U, Nal Colombia. Proyecto de grado. Bogotá.

Guiza, G.S.Y.; Barbosa, W.; Peña, L. & Díaz, M. (1996). Caracterización Estratigráfica, Estructural y Geoquímica de la Zona Comprendida entre Tunja y Paz del Río (Boyacá). VII Congreso Col. Geología. Tomo III.

Rezoni, C. (1981). Geología del cuadrángulo J-12 Tunja. INGEOMINAS, Bol. Geol., 24 (2). (escrito 1967) Bogotá.

Van Der Hammen, T. (1960). Estratigrafía del Terciario y Maestrichtiano Continentales y Tectonogénesis de los Andes Colombianos. Bol. Geol. Vol. 1-3. Bogotá.

GEOCHEMICAL SURFACE SURVEY EASTERN CORDILLERA BASIN, SOÁPAGA AREA[1]

HIDROGEOLOGÍA, GEOLOGÍA, AMBIENTAL LTDA – HGA LTDA.

2006

INTRODUCTION

The sampling of canned gas in free space is one way of analyzing volatile compounds linked to a sample without the use of extraction by solvents. The term "headspace" refers to the free space between the upper part of the liquid or solid content and the lid of a tin can. This technique is usually referred in the pharmaceutical ambit as headspace gas chromatography, and the objective is to analyze the vapor of the substance present in the space between the level of the liquid (or solid) and the lid of a tin can.

OBJECTIVE

Acquisition of 320 soil samples and processing by headspace gas chromatographic analysis with the purpose of detecting and quantifying present light gases.

LOCATION

The sampling area is located in Boyacá Department (Figure 1), and it is surrounded within the polygon with coordinates (origin Bogotá) that are presented in Table 1.

---

[1] Estudio geoquímico de superficie. Cuenca Cordillera Oriental, Área Soápaga y Cuenca Chocó, Área San Juan. HGA Ltda. Mayo, 2006.

Table 1. Polygon of the sampling area

VERTEX	NORTH (m)	EAST (m)
P1	1172304	1139300
P2	1172213	1155206
P3	1149771	1154337
P4	1133454	1143459
P5	1133408	1139346
P6	1124998	1139437
P7	1124998	1121520
P8	1139898	1121612

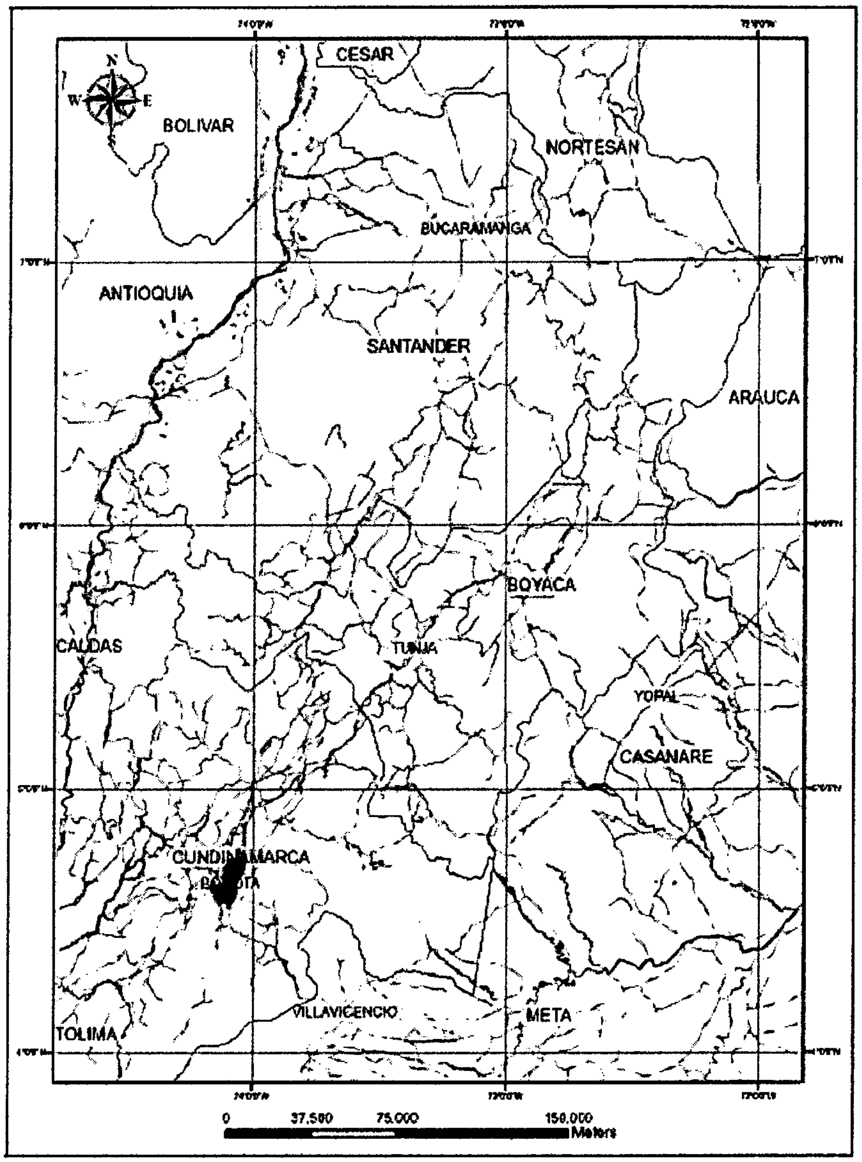


Figure 1. Location of the study.

METHODOLOGY

The steps followed during the acquisition, processing and interpretation of geochemical data are presented as follows:

1) Sampling

- Initially, a sampling grid based on previous geological studies, which define structural characteristics having possible exploratory interest. This grid includes 9 sampling lines: 7 of E-W direction, perpendicular to the main faults, and 2 N-S direction. The distance between the sampling lines is approximately 2 km and between the sampling points, at each line, is 500 m.
- From this grid, having the location of the sampling points, sampling points were consecutively enumerated, naming the first point S-1, and the last sample S-320. Later on, the Bogotá origin coordinate of each point was read. A listing of coordinates was generated with which later on, each GPS was loated daily, according to the points assigned to each geologist for field sampling.
- Before starting the sampling, a stage of area recognition was carried out with the purpose of designing the sampling strategy according to the accesses. This was done in order to obtain the corresponding permits to have access to the properties involved in the sampling, to hire auxiliary personnel and vehicles and to choose the base sites.
- A manual auger was used for the drilling of holes, which have depth between 0.80 and 1.50 m and are approximately 15 cm in diameter. The end depth of the hole is determined by getting to the fresh soil layer, which allows taking the no-contaminated sample, such as possible organic matter from the upper part.
- At each sampling point, approximately 250 g of soil was gathered and put into a tin can with a perforated lid. Before closing the tin can, the sample was diluted in water, filtered and preserved by way of a bactericide in order to avoid microbial degrading of the gases. With the same characteristics, an additional sample or safety countersample was taken, in case it would be needed to repeat the analysis or for an additional special analyses.

2) Data processing

- Chromatographic analysis of 320 samples of gas obtained from soil samples.
- Determination of the composition of said gases and quantify their concentration.
- Determination of the genesis of methane through analysis of carbon isotopes.

3) Interpretation

- Revision of results on the data table.
- Determination of Bernard's humectation index, and estimation of the type of hydrocarbon (biogenetic/mixture or thermogenetic).
- Filtering of database.
- Statistical treatment.
- Determination of the depth constant, the first and second order anomalous values for each one of the gasses (C1 to C5).
- C1, C2, C3, iC4, nC4, iC5 and C5 gas cartography and overpressure of C2 - C5 gasses.
- Evaluation chromatographic profiles.
- Cartography and description of areas of interest.
- Determination and plotting of relations.

RESULTS

Chromatographic analysis

For this analysis, a Hewlett Packard series 5890 II chromatograph was used, equipped with a flame ionization detector (FID) and one PLOT capillary column, having a stationary stage of alumina of 50 m length and a 0.53 mm inside diameter.

The *ChemStation* program receives and integrates the signal sent from the gas chromatograph, identifies and quantifies the concentration and shows a graphic representation of the results (chromatogram). The light hydrocarbons in the sample (methane, ethane, propane, acetylene, isobutane, butane, isopentane,

pentane and hexane) were quantified according to a certified standard. The equipment was calibrated every 15 samples, and a blank sample was run every 10 analyses. The data obtained from the chromatographic analysis were organized in tables, which were used for chromatographic profiles and interpretation. The interpretation took into account the following:

Determination of the background constant and anomalies was carried out based on statistical treatment. The obtained values are shown on Table 2.

Table 2. Values of anomalies.

Gas	**Mean**	**Standard Deviation**	**2nd order Anomaly**	**1st order Anomaly**
	μ	σ	$\mu + 2\sigma$	$\mu + 3\sigma$
Methane	10.57	5.79	22.15	27.94
Ethane	1.58	1.13	3.84	4.97
Propane	0.63	0.65	1.93	2.58
Acetylene	0.07	0.14	0.35	0.49
Isobutane	0.25	0.77	1.79	2.56
Butane	0.51	0.55	1.61	2.16
Isopentane	0.09	0.10	0.29	0.39
Pentane	0.32	0.27	0.86	1.13
Hexane	0.19	0.39	0.97	1.36

Once the background constant and the grade of the first and second order anomalies were defined, contour and classes maps for all the thermogenetic gasses were elaborated. Figures 2, 3 and 4 show examples of the obtained maps:

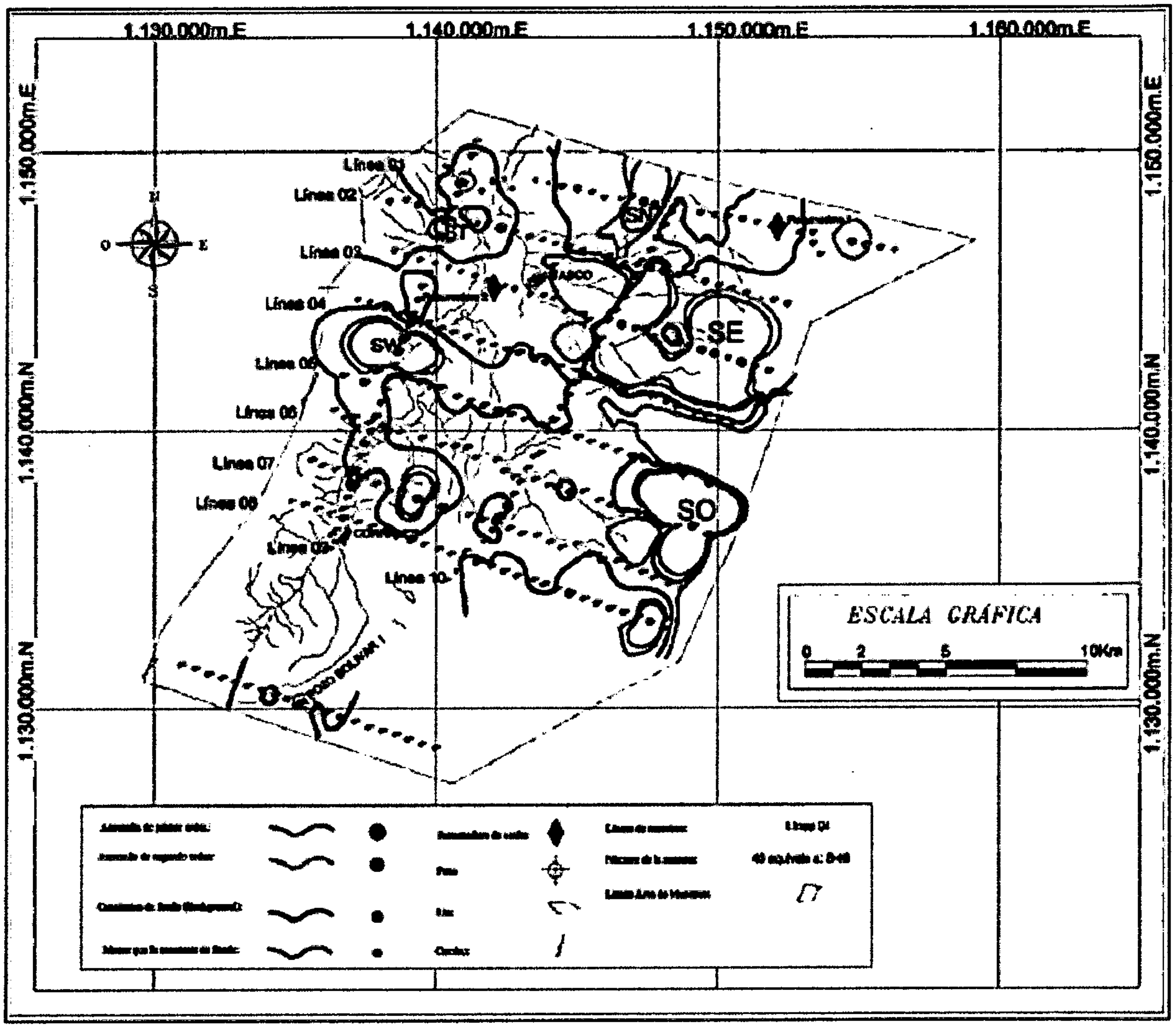


Figure 2. Map of clasess and contours of metane.

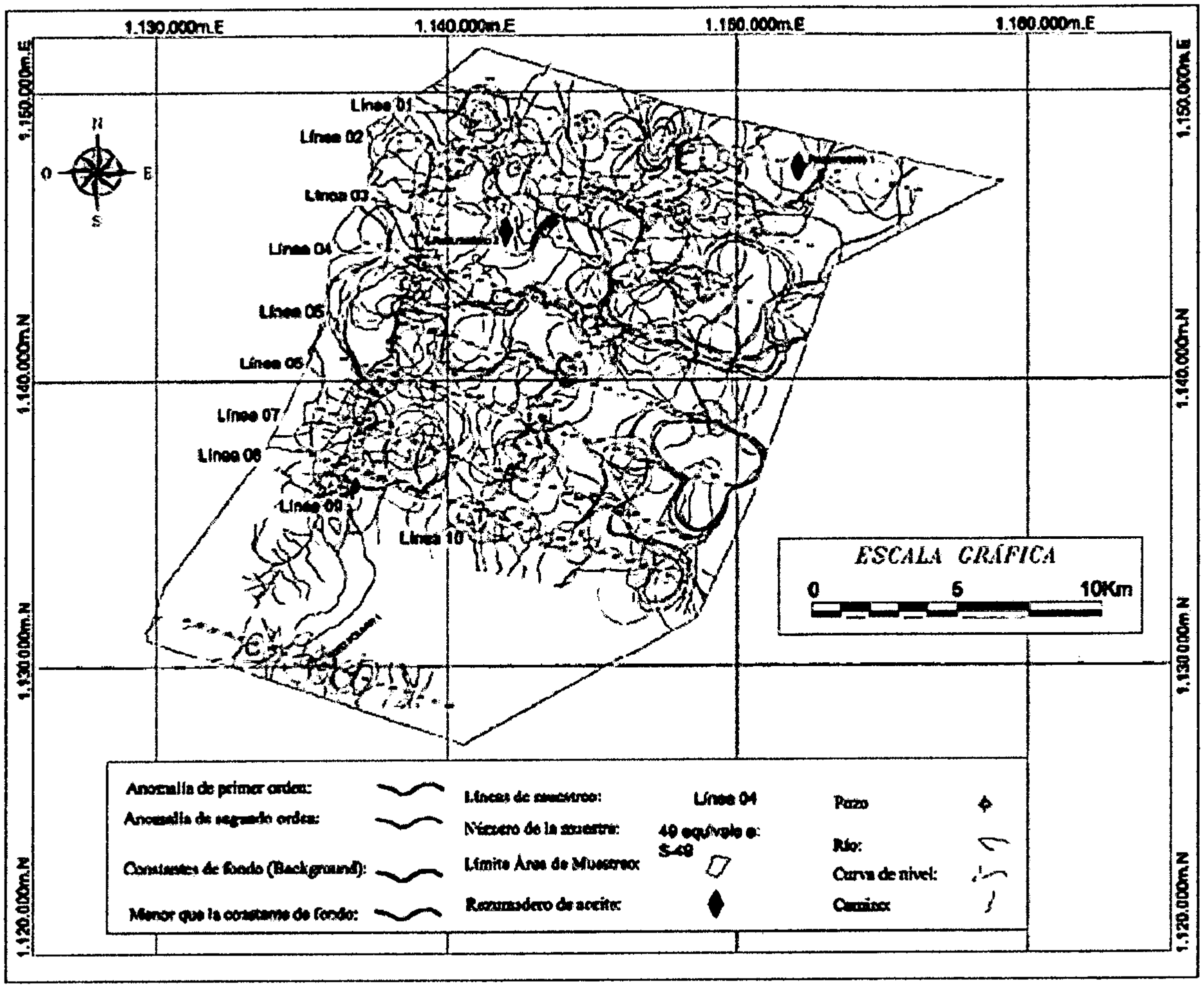


Figure 4. Map of supeposition of C2 to C5 contours.

The interpretation of the chromatographic data of the soil gas samples, evaluated in the present study, allows identification of 13 areas, which have anomalies of gases, mainly of methane and ethane (Figure 5).

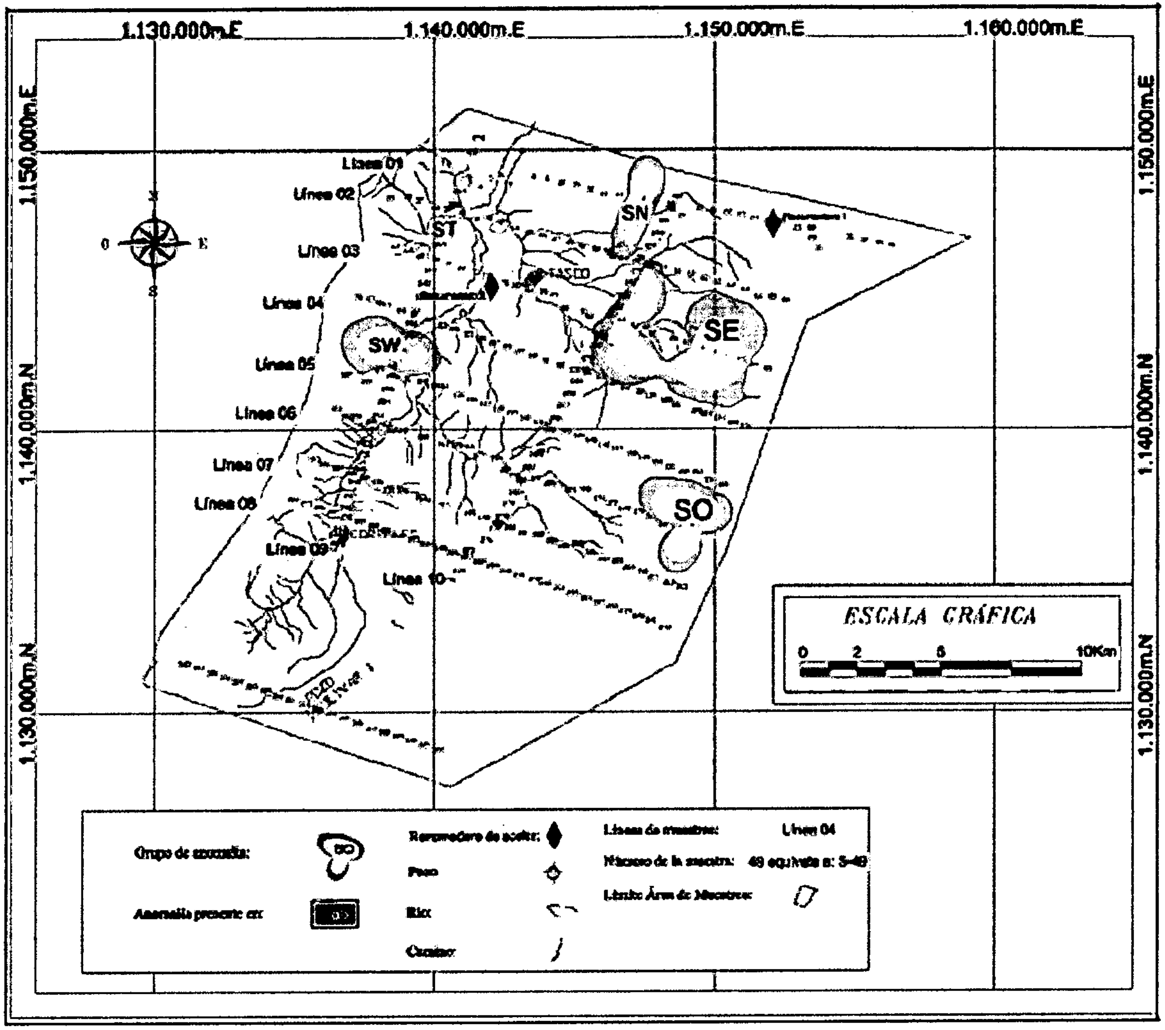


Figure 5. Map of areas of interest

Hydrocarbons Origin

According to Whiticar (1994), the relative proportion of C1-C4 saturated alkanes within a gas sample provides an initial classification of the origin of gas. Bernard (1978), uses the C1/(C2 + C3) ratio for describing the humectation ratio, amongst others, of the surface emanation gasses and sediments and for estimation of their origin (Table 3).

Table 3. Ratio. Bernard's parameter.

Ratio (Barnard's Parameter)	**ORIGIN**			
	Biogenetic	**Mixture**	**Diagenetic**	**Thermogenetic**
C1/(C2+C3)	>1000	100 - 1000	50 - 100	0 - 50

By applying this ratio, 5 (1.5%) samples, amongst the total of the 320, were identified, distributed as follows: 1 sample of gas (0.3%) of possible misture; 4 (1.2%) that would have diagenetic origin, being the rest (98.5%) of the gas samples of thermogenic origin.

Lastly, based on considerations presented by Harworth et al. (1985), it is possible to estimate that the type of fluid expected for this study area, would be predominantly oil and condensed

CONCLUSIONS

- The interpretation of the evaluated area in this study, allows identification of 5 areas with anomalous values of gases.
- The anomalies in the eastern side of the study area aligned in north-south direction correlate with the faults, that can be seen in the geological map.
- 98% of the 320 analyzed samples have a thermogenic character, and there are no signs of microbiological origin gas.
- The type of fluid expected for this area would be predominantly oil, with some minor quantity of residual oil, gas and condensate.

REFERENCES CITED IN THE ORIGINAL WORK

Duchscherer, W. Jr. (1984). Geochemical hydrocarbon prospecting, with case histories: Tulsa, PennWell Publishing Co., 196 p.

Haworth, J. H., Sellens, M. and Whittaker, A. (1985). Interpretation of Hidrocarbons Shows Using Light (C1 – C5) Hidrocarbons from Mud – Log Data, AAPG Bulletin, V.69, No.8, pp. 1305-1310.

Krumbein W. C. and Graybill, F. A. (1965). An Introduction to Statistical Models in Geology.

Isaaks, E. H. and Srivastava, R. M. (1989). An Introction to Applied Geostatistics.

Schumacher, D. and Abrams M. A. (1996). Hydrocarbons Migration and its Near-Surface Expression, AAPG Memoir 66.

Whiticar, M. J. (1994). Correlation of Natural Gases with their Sources, Chapter 16, en Magoon L. B. and Dow. G. W., The Petroleum System – From Source to Trap, The Petroleum System: Memoir 60.

PETROGRAPHIC AND PETROPHYSICAL ANALYSIS OF OUTCROP SAMPLES OF GEOLOGICAL CARTOGRAPHY PROJECTS – SOÁPAGA AREA[1]

C & CO SERVICES LTDA.

www.cycoservices.com

2007

GENERAL OUTLINES

The intention of present work is to integrate the petrographic and petrophysical studies and analysis of rock samples collected during geological cartography works, stratigraphical surveys and geological control in the seismic lines of the Soápaga Area – Eastern Cordillera Basin. The integration refers to each potential reservoir formation of the basin.

The rock samples studied in this project mostly correspond to siliciclastic rocks and in less proportion to calcareous rocks. The evaluation of the reservoir quality in every single formation allows getting from low to high, being rated the basin as high quality of the reservoir in the basin.

OBJECTIVE

To evaluate the reservoir quality of the basin by means of petrographic and petrophysical analysis.

METHODOLOGY

The following analyses and parameters for each reservoir formation were integrated and evaluated:

[1] Análisis petrográficos y petrofísicos de muestras de afloramiento de los proyectos de cartopgrafía geológica en: Grupo 1. Área Soápaga. Informe Final. C&CO Services Ltda. Agosto, 2007.

Petrographic: Depositional or detritus textures, diagenetical textures detritus composition or minerology, diagenetical composition or mineralogy, matrix types, cement types, porosity and pore types, porosity results (Petrograpical method or thin-section).

Petrophysical: Porosity, permeability, grain density, fluid saturation with retort.

Sedimentological: Lithofacies, lamination type or internal sedimentary structure, bioturbation and bioturbation intensity, stratigraphic column.

In order to classify the quality of the rock, the Winland correlation between porosity, permeability and the size of pore throat was applied, defining 5 categories to which different colours were assigned according to the following ranks:

Table 1. Criteria for the classification of samples by rock types

	Clasification	R35 Winland	Permeability
1	Very Goog	>8 µm	> 250 mD
2	Good	4 – 8 µm	50 – 250 mD
3	Regular	2 – 4 µm	10 – 50 mD
4	Bad	0.5 – 2 µm	1 – 10 mD
5	Very Bad	< 0.5 µm	< 1 mD

The Bioturbation levels mentioned in this report are according to the diagram shown in Figure 1.

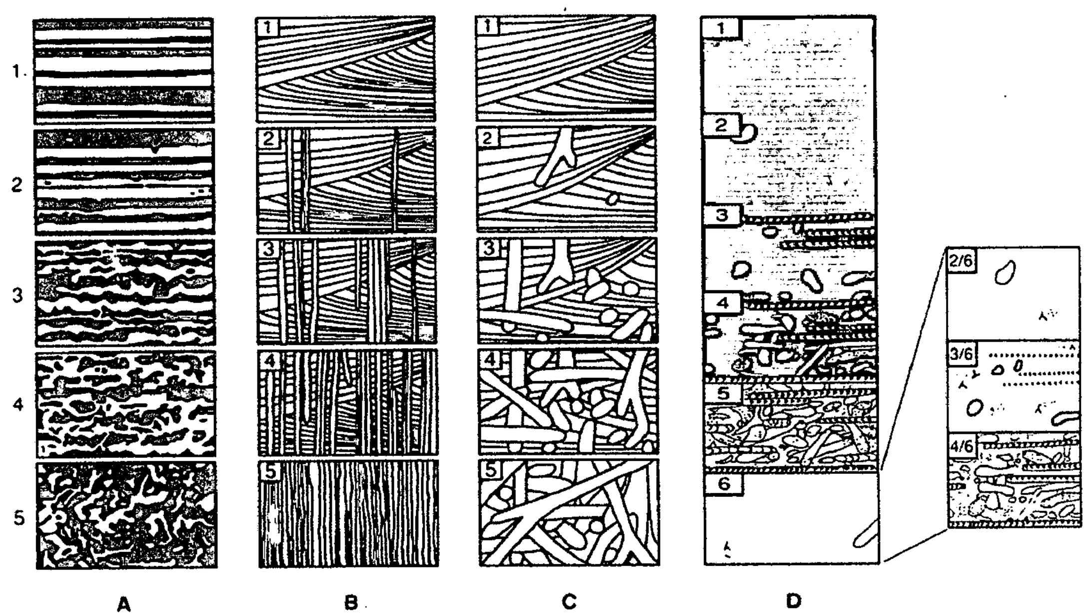


Figure 1. Schematic diagrames estimated from the bioturbation grade (ichnofrabric index). (A) Layers with thin lamination. (B) Layers with big thikness dominated by skoliths. (C) Layers with big thikness dominated by *Ophiomorpha*. (D) Deep water with fine grain environments.

A total of 277 samples were analysed (Table 2).

Table 2. Analyzed samples from the Soápaga Area – Eastern Cordillera Basin.

FORMATION	ANALYSIS	
	PETROPHYSICS	PETROGRAPHY
Busbanza Filites and cherts	1	0
Tibet	11	0
Floresta	6	0
Cuche	12	0
Girón	9	0
Tibasosa	20	4
Une	39	12
Chipaque	5	0
Plaeners	5	3
Los Pinos	14	5
Arenisca Tierna	15	6
Guadalupe	4	0
Guaduas	8	4
Socha Inferior	11	0
Arenisca de Socha	52	23
Arcillas de Socha	6	0
Picacho	45	15
Concentración	13	3
TOTAL	**277**	**78**

RESULTS AND CONCLUSIONS

Reservoir Quality in the Basin

The rock samples from the formations studied in this Project mostly correspond to siliciclastic rocks.The quality evaluation of reservoir in every single formation allows getting a variation from low to high. High quality of the reservoir prevailed in the basin. The Tibasosa, Une, Los Pinos, Arenisca Tierna, Areniscas de Socha, Picacho and Concentración formations feature the best aspects and the best data density; displaying from very low to high porosity measures (0.2-36.3%) and from very bad to very good permeability (<0.001 -2413mD). The best samples are located in the Escuela Bellavista-Corrales, Loma El Tahúr-Tasco, Quebrada Canelas-Tasco, Corrales-Tasco, Cosgua-Tasco and Puente Cajones-Tasco regions. The Cuche, Chipaque and Guaduas formations show very good features but low data density, which does not allow to conclude about the reservoir quality (Figure 2).

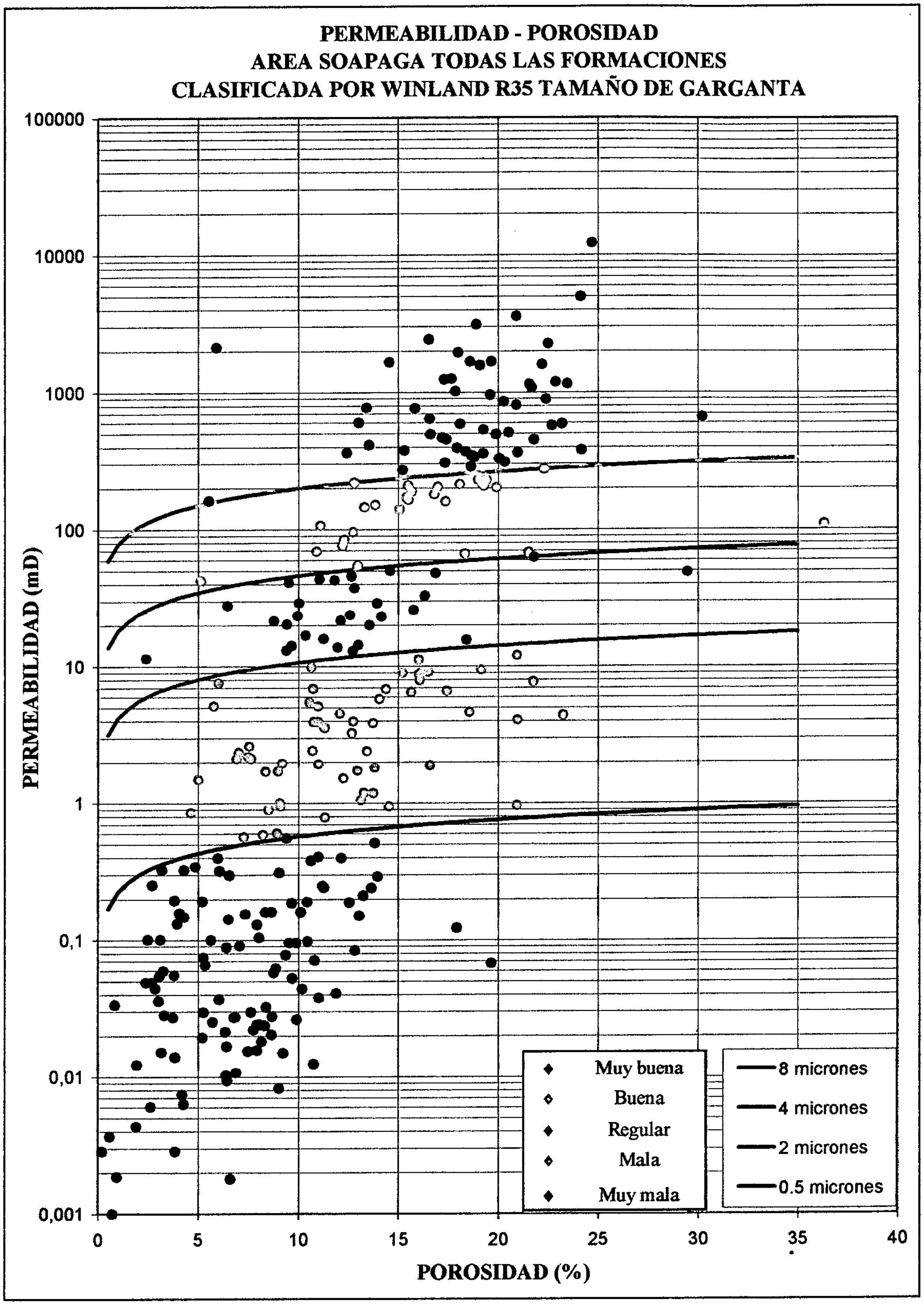


Figure 2. Porosity and Permeability of the rock samples from the Soápaga-Eastern Cordillera Basin.

The reservoir quality according to the formation are shown on the Table 3.

Table 3. Reservoir quality.

FORMATION	RESERVOIR QUALITY
Tibet	Very low
Floresta	Low
Cuche	Low
Girón	Low
Tibasosa	High
Une	High
Chipaque	Variable (Moderate – High)
Plaeners	Low
Los Pinos	High
Arenisca Tierna	High
Guaduas	Moderate
Arenisca de Socha	High
Arcillas de Socha	Low
Picacho	High
Concentración	High

REFERENCES CITED IN THE ORIGINAL WORK

Folk, R. L. (1974). Petrology of sedimentary rocks: Austin, texas, hemphill's Book Store, 170 p.

Geostudios Ltda. (2006). Cartografía geológica cuenca cordillera oriental-sector Soápaga.

SOÁPAGA 2D 2005[1]

SISMOPETROL S.A. **PGS**

www.sismopetrol.com **www.pgs.com**

ALBORADA PROVISIONAL JOINT VENTURE

2006

OVERVIEW

The SOÁPAGA 2D seismic program involved a total of 5345 shot points, divided in 11 lines, with an extension of 224.1 km. The program was located between the cities of Sogamoso on the south side of the block, and North Sátiva, within a path of about 25 km wide, parallel oriented to the Soápaga Fault. The Project's geographic location and the map of this seismic Project are shown respectively in Figures 1 and 2.

OBJECTIVE

The aim of this work is to carry out the geological surface control, and obtain the map of geological features, as well as the geological profiles along the seismic program Soápaga 2D lines in a Sector of the Soápaga Block in the Eastern Cordillera Basin.

LOCATION

The Soápaga Block is located northeast of Tunja Town in the Boyacá Department, near the border with the Santander Department (Figure 1).

[1] Soápaga 2D 2005. Informe Final. Grupo SP-336. Floresta-Boyacá. Octubre, 2006

The study area is located into the jurisdictions of Belén, Betéitiva, Busbanzá, Cerinza, Duitama, Floresta, Gámeza, Sogamoso, Monguí, Nobsa, Paz del Río, Santa Rosa de Viterbo, Sátiva Norte, Sátiva Sur, Socha, Susacón, Tasco, Tibasosa, Tópaga, and Tutazá municipalities. The study zone is surrounded by an irregular line, whose vertices are shown in Table 1. Its total surface area is arround 237136 km^2 and corresponds to the IGAC topographic planes No. 172 and 152 (scale 1:100000).

Table 1. Coordinates of the study area.

Vertex	East	North
A	1137109	1179543
B	1162708	1169508
C	1136656	1117618
D	1111082	1127673

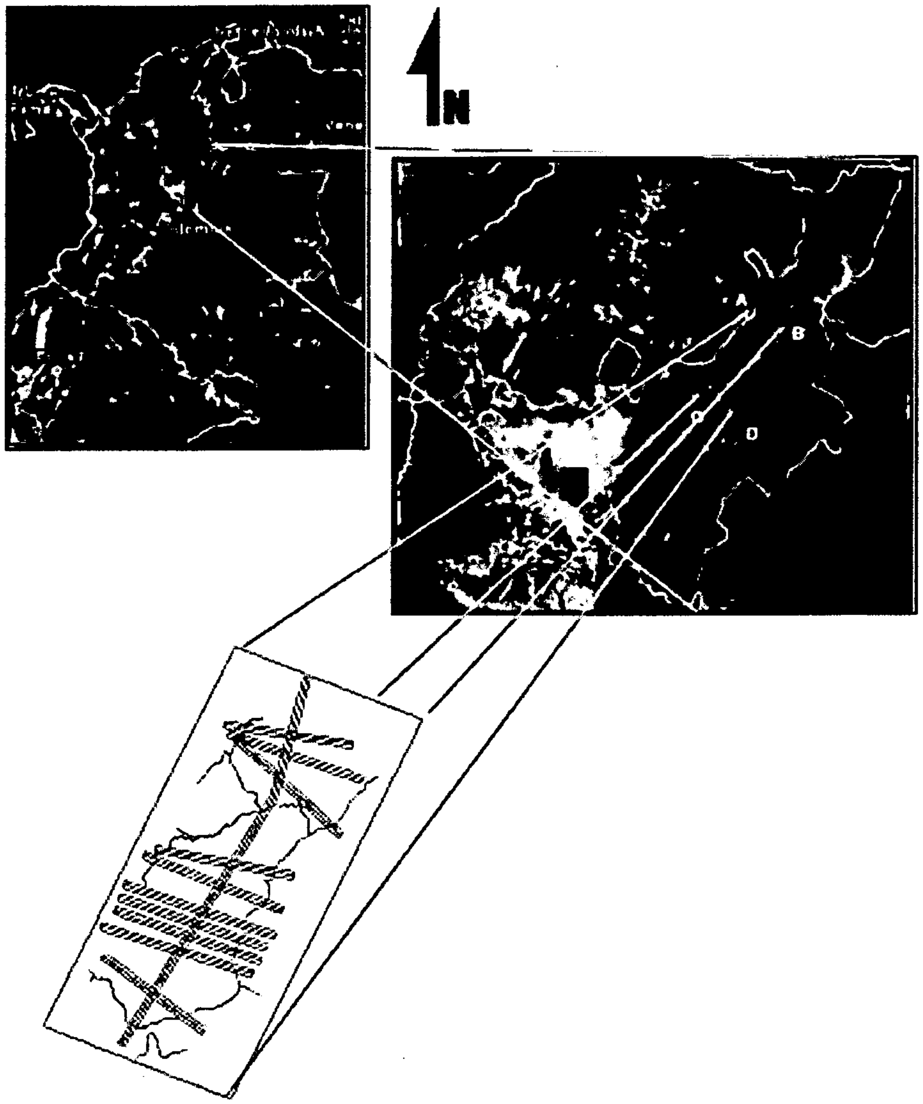


Figure 1. Location of the Project.

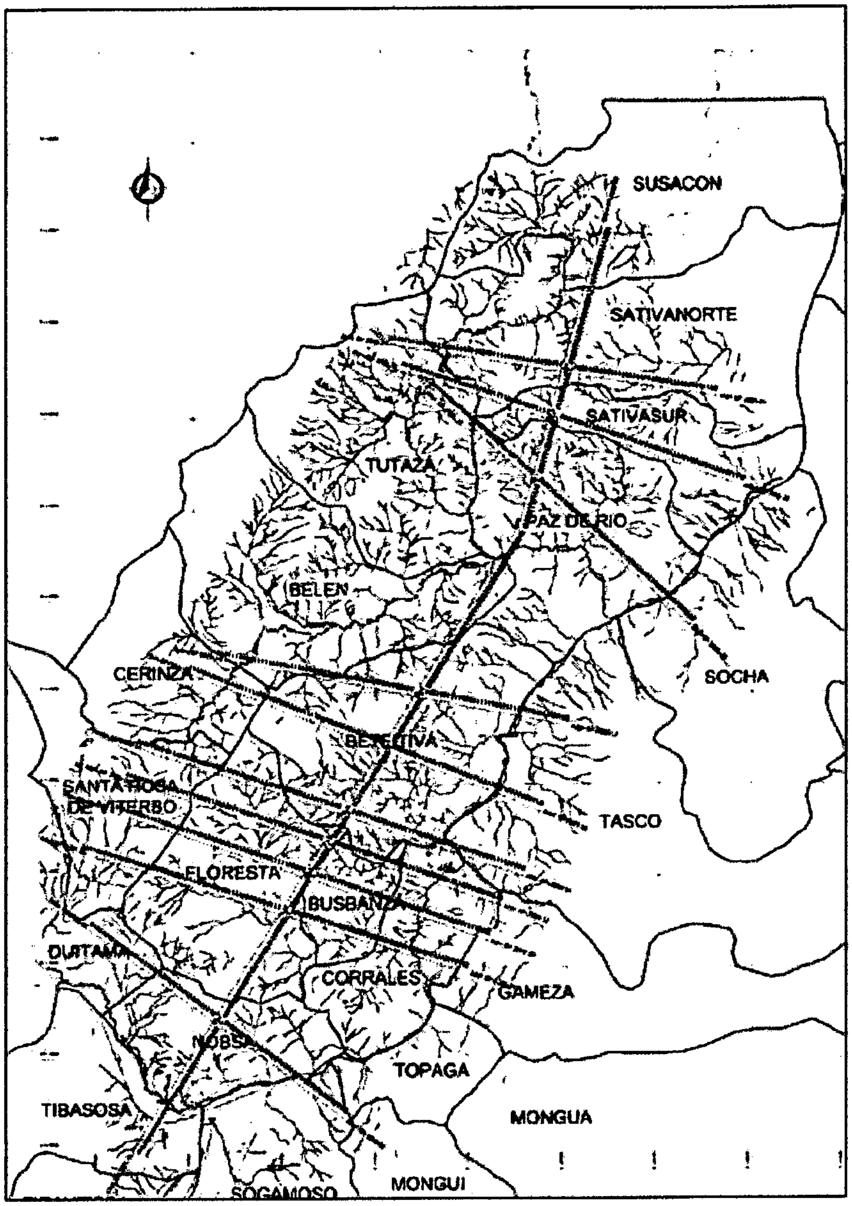


Figure 2. Seismic Project´s Map. SOÁPAGA 2D.

Geologic Frame

In the study area, rocks from the Precambrian to the Tertiary Ages outcrop, including quaternary sediments of glacial, alluvial, colluvial, and gravitational origin. From a structural point of view, the presence of complex systems of geological faulting stood out.

Duque (1990a, b)) also appears. The biostratigraphy has similar basic references to Petters and Sarmiento (1956) and Duque-Caro (1971, 1975, 1990a, b), covering reference sections of Carmen-Zambrano, and those of the Atrato River Basin, until now the best sections and reference areas for biostratigraphic studies of the Colombian Pacific and Caribbean coasts, which have been updated with the modern planctonic biostratigraphy data of Blow (1969), Bolli el *al.* (1985) and Berggren et *al.* (1995). The information referring to each lithostratygraphic unit includes: lithology, age, thickness, deposition environment, author, and location.

Stratigraphic columns

That the facies interpretation has to give information about the possible (generally hydrodynamic) conditions of the bottom layers, where rocks were accumulated, and by means of interpretation of the facies associations an idea about the depositional processes of the way the rock successions were formed may be obtained. The main evidence used to identify the bottom of the deposit of the surveyed stratigraphic sections was the foraminiferal analysis. Figure 3 provides, as an example, the Malambo stratigraphic column.

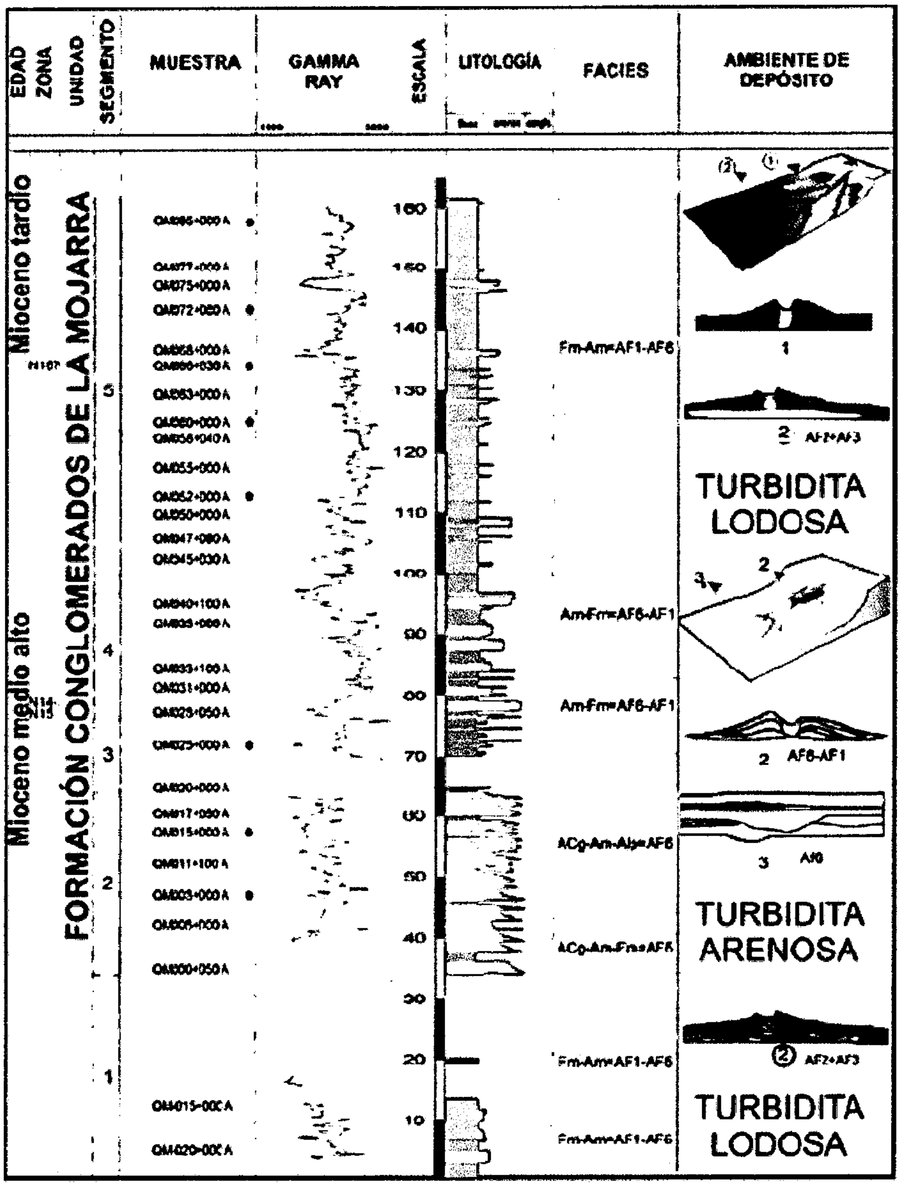


Figure 3. Malambo stratigraphic section.

Petroleum Geology

The sequence that underlies the outcropping units in the present study can potentially contain reservoir or source rocks. Below extensive Quaternaries, found during the stratigraphic surveys, sandy and muddy sequences, that could possibly serve as reservoirs or sources, can be displayed as well

<u>Sources</u>

In the field, only rocks of Miocene age or younger were observed. Out of these units, the Condoto Formation is probably the best generating unit found in the present study. The sedimentary rocks of this unit could contain organic matter derived from maritime organisms, which would define the possible type of produced kerogene (type II - III).

Reservoir

Outcrop rocks, which are potentially reservoir in the area, correspond to the Conglomerados de la Mojarra Formation, whose visually-estimated porosity is considered medium to poor, it displays abundant sand layers with variable thicknesses with small lateral extension. Nevertheless, some sandy levels of the Istmina Formation, which display thicknesses of up to 60 cm should not be discarded. These formations were observed mainly in isolated outcrops at the Docampadó River, as well as the Bicordó River. Cossio (2003) reports sandy thicknesses of up to 5 m in this unit. Additionally, in units that do not outcrop in the area as the Iró and Sierra formation ones, have been also considered as potentially source rocks (Repsol, 1996; Texas, 1989; Suárez, 1990).

Seals and Traps

Pelitical rock sections within a Tertiary sequence (Istmina, Condoto, Conglomerados de la Mojarra formations), act as the most important seals in this area. As structural traps we can visualize the outlying block between the Bicordó and Agua Clara faults; structures like the Siguirisua Anticline and the Docordó Anticline.

Seeps

No hydrocarbon signs were observed.

Other signs

Samples of gas and petroleum were found on the Buchado-1, Chagui-1 and Majagua-1 ANH (2007) wells.

CONCLUSIONS AND RECOMENDATIONS

- The present field work modifies the maps previously developed by INGEOMINAS regarding the stratigraphic units, which could be defined and correlated in agreement with the biostratigraphic zonation obtained during this project. The new map generally improves the knowledge about contacts, field data (many of which have been re-considered), structural boundaries and rock ages, which allow diminishing considerably the exploratory risk in search of any non-renewable resources.

- According to the analysis of the columns, the biostratigraphic results and the cartography executed in the northern-sector, a sequence with mud predominance named Condoto and another sequence with predominance of slime was interpreted, which, according to the performed biostratigraphic analyses is the oldest formation outcropping in the area (called Istmina).
- The straight or linear character of the surface faults suggest these are mainly high-angle faults. The displacement values of these faults are unknown.
- In general terms, the results of this work modify some aspects of the previously-developed maps as far as the structural profiles, the completion of faults and their closings, and the presence or absence of some specific structures.
- In general, it is reasonable to say that all the Gamma Ray recording curves of the different surveyed and interpreted columns have sawed-off and irregular forms, since the alternation of muds and sands is constant.
- The Th values are the highest ones in every sequence, but with different lithological correspondence.
- The biostratigraphic zonation allowed to differentiate several mapped units and to confirm again the fast facies changes that occur specially between Conglomerados de la Mojarra and Condoto formations. The sterile character of the Mayorquín and Raposo formations helped their differentiation in zones of limited outcrops.

REFERENCES CITED IN THE ORIGINAL WORK

Agencia Nacional de Hidrocarburos (ANH), 2007. Colombia Oil & Gas, Folleto Chocó Basin.

Berggren W. A., Kent D., V. Swisher; I. I. I., CC and Aubry, M.-P., 1995. A revised Cenozoic geochronology and chronostratigraphy: Society of Economic Paleontologists and Mineralogists, Special Publication, v. 54, pp. 129-212.

Blow W. H., l969. Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. In P.

Bolli H. M.; Beckmann J. P. and Saunders J. B., 1994. Benthic foraminiferal Biostratigraphy of the south Caribbean region: Cambridge, Cambridge University Press, 408 p.

Cossio, 2003. Geología de las planchas 201, 202, 221, 222. PDF.

Duque-Caro H., 1971. A reply to: On planktonic foraminiferal zonation in the Tertiary of Colombia. Micropaleontology, vol. 17, pp. 365-368.

Duque-Caro H., 1975. Los foraminíferos planctónicos y el terciario de Colombia: Revista Española de Micropaleontología, v. 7, pp. 403-427.

Duque-Caro H., 1990a. Neogene stratigraphy, paleoceanography and paleobiogeography in northwest South America and the evolution of the Panama seaway: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 77, p. 203-234.

Duque-Caro H., 1990b. The Chocó block in the northwestern corner of South America: structural, tectonostratigraphic and paleogeographic implications: Journal of South American Earth Sciences, v. 3, pp. 71-84.

Petters V. and Sarmiento R., l956. Oligocene and lower Miocene biostratigraphy of the Carmen Zambrano areas, Colombia. Micropaleontology, v.2, pp. 7-35. New York.

REPSOL, 1996. Informe Final Geología y Geofísica Contrato de Asociación Chocó Central. PDF.

Suárez Rodríguez M., 1990. Columna Estratigráfica Generalizada de la Cuenca del Atrato 1990. PDF.

TEXAS PETROLEUM COMPANY, 1989. Informe Geológico. Área de Asociación Istmina. PDF.

GEOLOGICAL CARTOGRAPHY OF THE AREA OF THE ATRATO-SAN JUAN SUB-BASIN, CHOCÓ DEPARTMENT. FIELD GEOLOGICAL INFORMATION INTEGRATION AND INTERPRETATION REPORT[1]

DUNIA CONSULTORES LTDA

Calle 64 No. 10-45 apto 302 Tel.: (57)(1)2556914

2006

SUMMARY

The study area is located west of Colombia, in the Pacific Coast, at the western flank of Western Cordillera. Cretaceous to recent units outcrop in the area. The oldest unit is the Santa Cecilia-La Equis Complex from the Upper Cretaceous, which makes up the western foothills of the Western Cordillera, and is located east of the worksite. The Tertiary Pacific succession outcrops in the San Juan River Valley. It is represented by the Iró Formation of the Upper Paleocene-Eocene, and by the San Juan Group of the Lower Miocene. The Santa Cecilia-La Equis Complex is made up of basalt, diabase, sinter, agglomerate with interbedded claystone and siltstone packing. The lower part of this unit is composed of claystone, siltstone, limestone, and sandstone with sporadically embedded pyroclastic material. The Iró Formation is composed of light grey to greenish limestone, cherts, light grey fissile claystone, and some sporadic sandstone packing. The San Juan Group is divided into three units: the Istmina Formation, the Conglomerados de la Mojarra Formation, and the Condoto Formation. Of the three units, two are present in the

[1] Cartografía geológica en el área de la Subcuenca Atrato-San Juan, Departamento del Chocó. Informe de integración e interpretación de la información geológica de campo. Dunia Consultores Ltda. June, 2006.

study area. The Conglomerados de la Mojarra Formation is the one that occupies the largest surface at the worksite (approximately 40% of the area). The Istmina Formation is made up of light and dark grey lithosandstone, siltsone and claystone. The Conglomerados de la Mojarra Formation is composed of a cluster of granulated conglomerates, pebbles conglomerate, and basalt blocks, diabase, pyroclastic rock, limestone, cherts and diorite. The tertiary concentration lies over the volcanic rocks of the Santa Cecilia-La Equis Complex. The area is located in the so-called Istmina Deformation Zone (Duque-Caro, 1990), a complex structural area. The structures of the area show a predominant N50E trend, with a slight east-west variation in the eastern sector, near the Western Cordillera foothills. Three regional structures are outstanding: the high angle inverse San Juan Fault, with NW trend, the La Mojarra Syncline, and the Ñápera Anticline, the core of which is made up of the most ancient rock in the study area: the Santa Cecilia-La Equis Complex. The last event developes in the area was manifested by inverse faulting with a significant dextral strike component. The most important main stress in this event had a strong N-S trend.

The Iró Formation shows evidence of hydrocarbon presence at the surface, namely dry oil in fractures, impregnated rock, and oil seep. Said evidence indicates the existence of hydrocarbon generation and migration in the basin through the fractures system, which also indicates the presence of porosity (secondary fracturing porosity), and optimal rock permeability in this unit.

LOCATION

The study area is located in the western part of Colombia, in the Chocó Department, in the upper San Juan River Valley, approximately 280 km west of Bogotá. The area is located south of Quibdó, the capital city of the department. It covers part of the jurisdictions of the Tadó, Istmina, Santa Rita, and Condoto municipalities, and Playa de Oro, La Esperanza, Santa Bárbara, Acosó, Santa Ana, and El Paso hamlets (Figure 1).

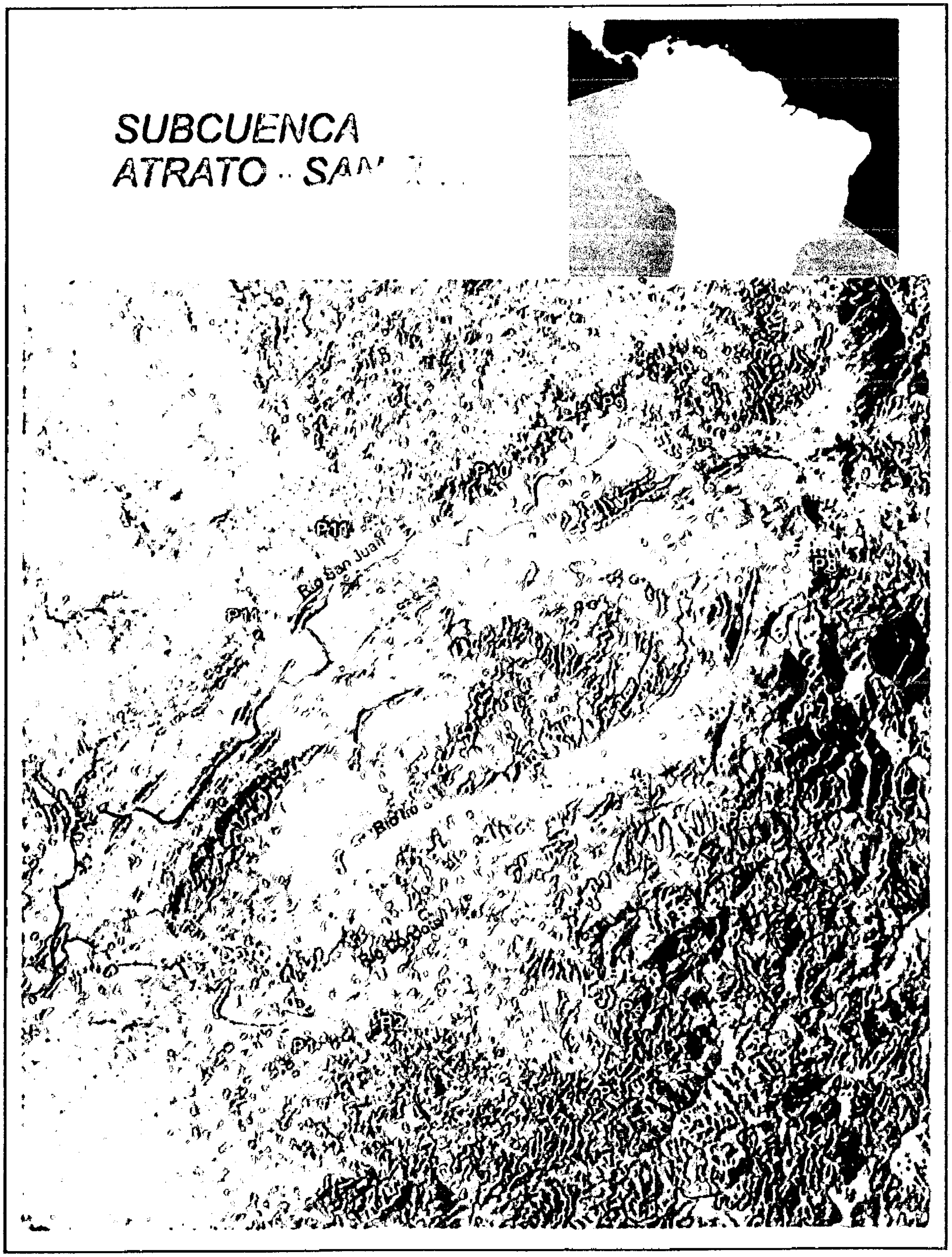


Figure 1. Radarsat image locating the study area.

Table 1 includes information about technical parameters used during the data acquisition:

Table 1. Acquisition Parameters.

Geometric Array	
Total amount of Live channels	800
Inline Covering	10
X line Covering	20
Nominal Fold	200
Bin Size (m) Inline	10
Bin Size (m) X line	20
Minimum Offset (m)	10
Maximum Offset (m)	8000
Record	
Record System	SERCEL SN 408
Low cut filter	Not Applied
Anti Aliasing Filter	0.8 N. Minimum Phase (200 Hz, 370 dB/octave)
Notch Filter	Not Applied
Pre-amplification Gain	12 dB
Sampling Interval	2 ms
Record Length	12 s.
Record Format	SEG D 8058 IEEE
Tapes	3490 E
Density	72340 BPI
Auxiliary Channels	2
Auxiliary 1	Decoder TB + Confirmation Time Break(CTB)
Auxiliary 2	Digital: Encoder (TB)
Shot System	PELTON SHOTPRO 2.0
Geophones	
Model	SM24
Configuration Setting	6 Serial geophones
Natural Frequency	10 Hz +/-2 % +/- 2.5 %
Open Circuit Damping	0.25
Damping with 1339	0.6 more 5/-0 %
Sensitivity	28.8 V/m/sec
Distortion	0.105 or less
Coil Resistance	375 Ohm
Damping Resistance	1000 Ohm

METHODOLOGY AND RESULTS

In general, the acquired seismic data is of good quality, taking into consideration the geologic complexity of the study area. Mainly, the presence of regional faults is clearly seen, and it is likely to interpret important geologic features in hydrocarbon exploration.

Performed tests

Among the tests that were undertaken, the following processes were included: Amplitude recovery, deconvolution, spectral whitening (TVSW), refraction statics, residual statics, DMO, migration and filters.

Figure 3 shows a typical record, and Figure 4 shows after stacking with amplitude recovery:

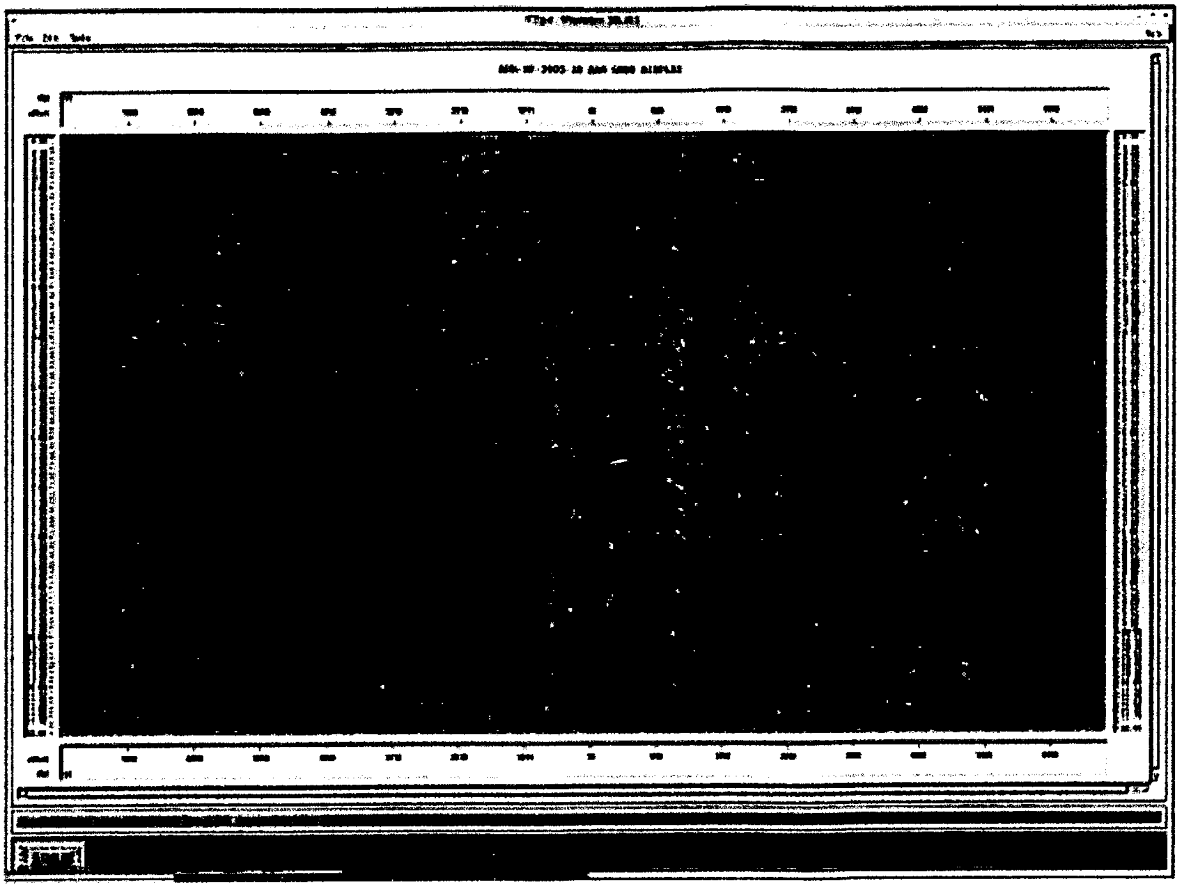


Figure 3. Typical record.

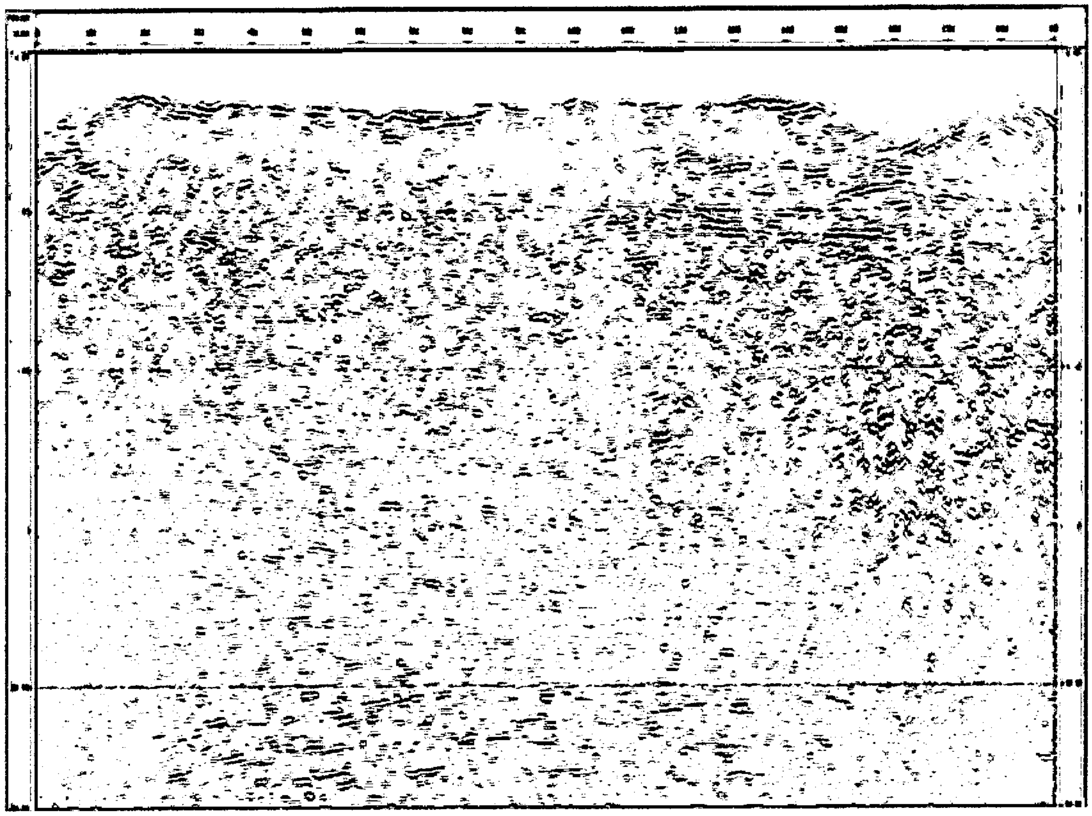


Figure 5. Stacking with deconvolution.

Refraction Statics

The presence of poorly consolidated or low velocity layers lead to static anomalies of short and long periods, which many times have wave lengths greater than an array, and can introduce false structures into the data. The most effective method to correct these anomalies is the refraction statics, which allows to obtain thickness and speed values of the superficial layers, analyzing the first arrivals, from which the statics can be estimated.

In order to estimate the refraction statics the *STRATUS* program was used. *STRATUS* uses the refractor times obtained from seismic data (first arrivals) to iteratively build and update velocity model of the ground. The Figure 6 depicts the velocity model within the first layer:

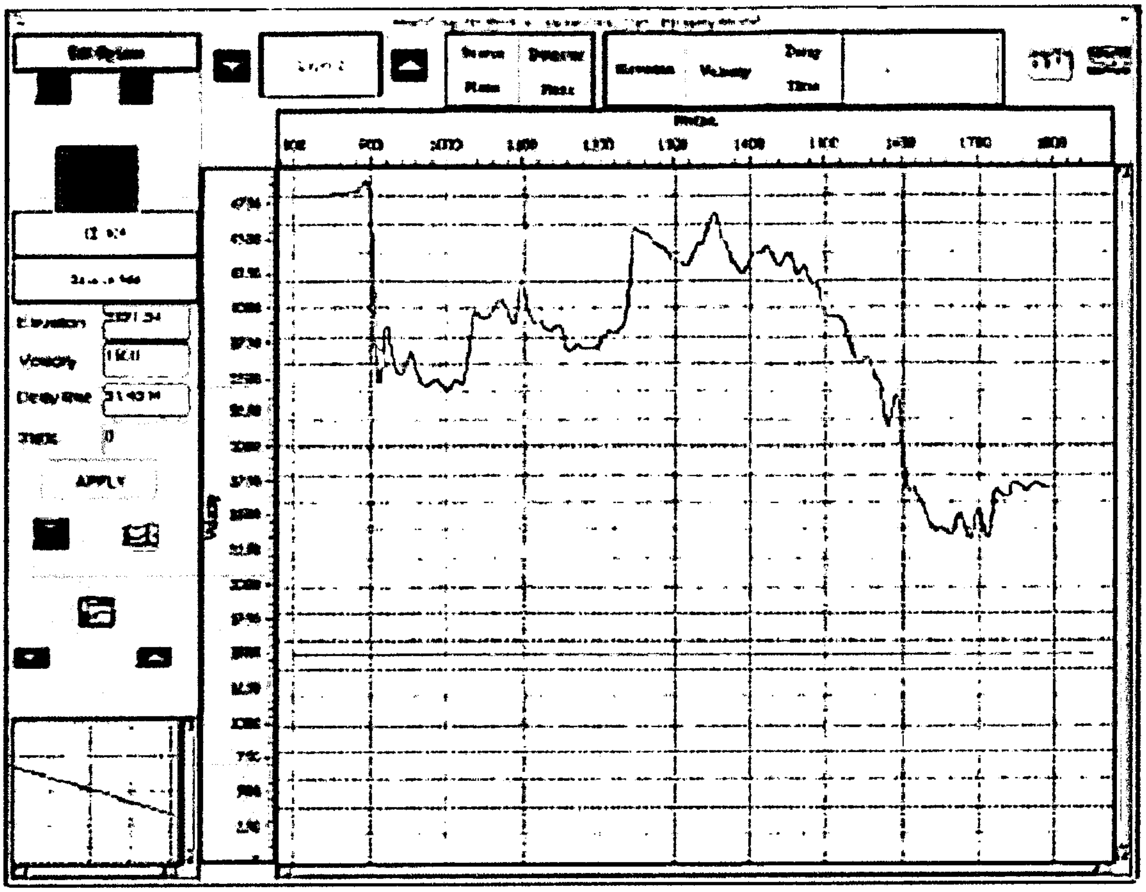


Figure 6. Velocity model whitin the first layer.

Here we can see that the refractor velocity varies between 2400 and 4800 m/s, which is consistent with the superficial geology.

The selected parameters to estimate the refraction statics are the following:

V_0 = 1500 m/s (Meteorized layer velocity).

V_1 = Variable (First refraction layer velocity, estimated by the program from the first picked arrivals).

V_R = 3400 m/s (Replacement velocity).

Refractor Offset Range: 200 a 1500 m.

Reference Plane: 4000 m.a.s.l. (Datum)

Residual Refraction

In practice, the statics refraction methods do not totally solve the high frequency statics, since these cannot properly correct the quick changes in elevation and velocity occurred on the superficial layers. Most of the residual statics techniques are based on the concept that the times on each trace consist of shot statics, a receptor statics, PRC statics, and residual NMO. All of these assume that the wave length of the residual anomaly is short enough to be contained within the PRC record. Figure 7 shows the first stacking with the first step of veolcity analysis and the first step of residual statics:

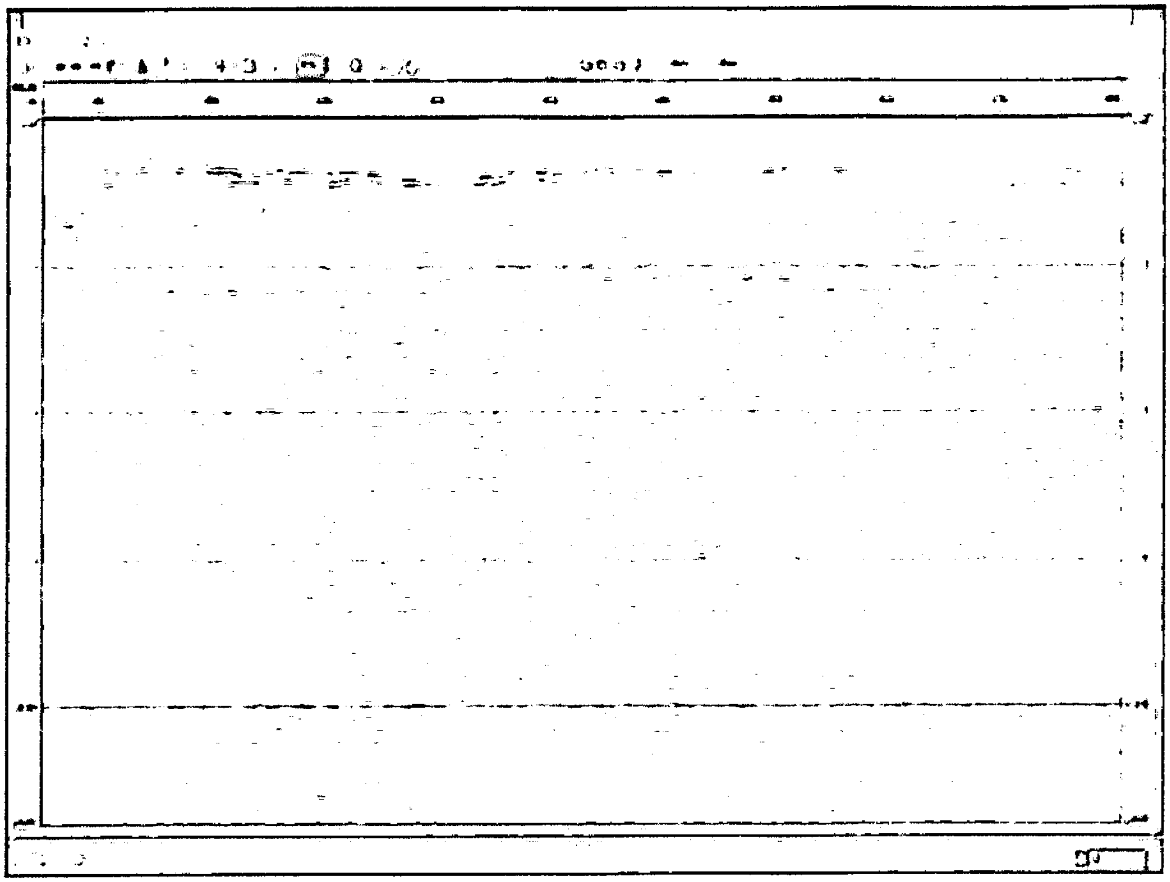


Figure 7. Stacking. First step of velocity analysis and first step of residual statics.

Migration

The migration process by finite differences is applied in two steps: the wave field extrapolation, and imaging. The extrapolation step consists of continuing downwards the wave field registered on the surface, and using scalar wave equation by a repositioning data recording plane. The imaging step consists of estimating the wave field corresponding to t=0 (Travel time = 0) of the repositioned recording plane. All data are recursively migrated, using an extrapolation output as input for the next one. The initial condition is fullfiled with the wave field on the surface z=0, the border condition is fullfiled assuming that the field is equal to zero after a maximum time of observation. Different algorithms and migration parameters were tested as follows:

Algorithm Type: Stolt Migration FK, Kirchoff Migration, Minimum Phase Migration, and Finite-difference Migration (FD).

Velocities: For all algorithms, different stacking velocity reductions were tested with 60%, 70%, 80%, 90%, 100%, and 110%. The best results were achieved with the post-stacking migration by finite differences with 70% of stacking velocity. Figure 8 corresponds to the migrated section.

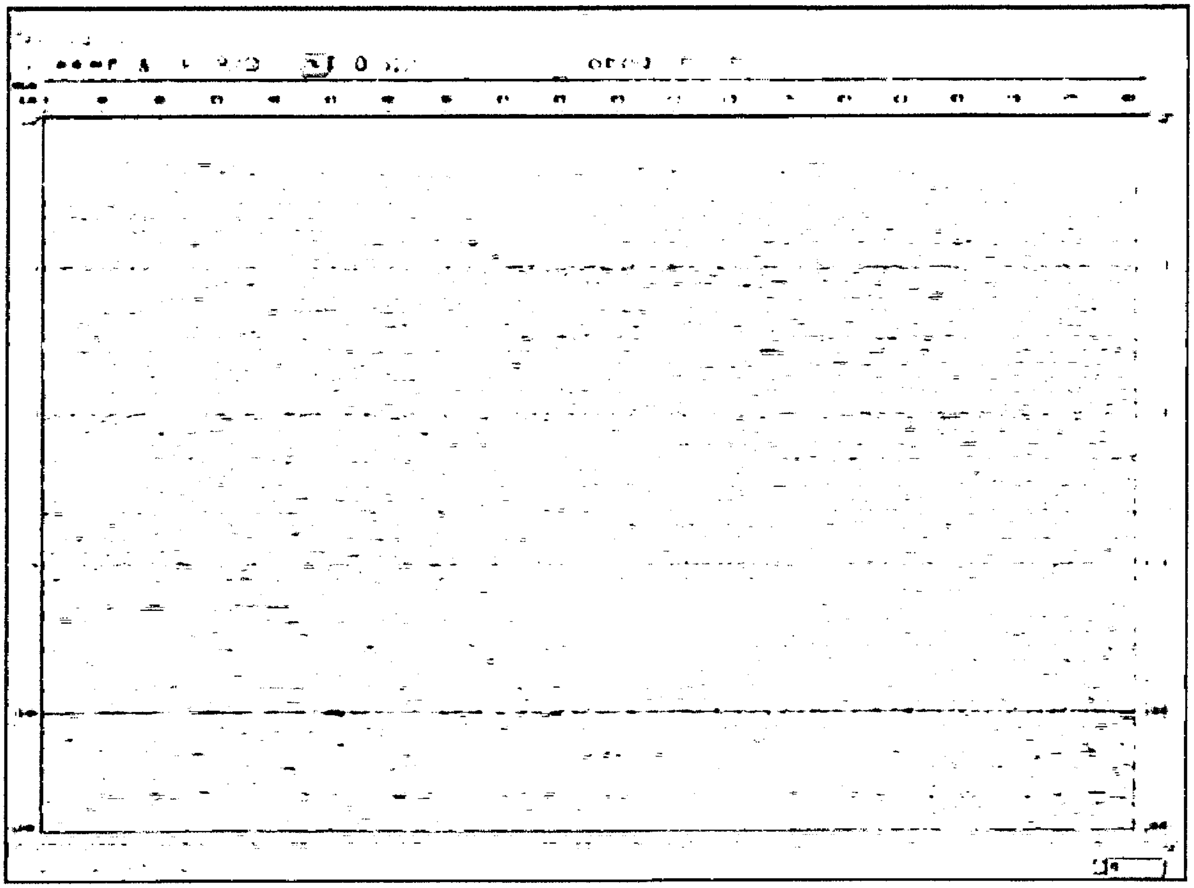


Figure 8. FD Migration 70%.

Processing Sequence Summary

Pre-Pile up

1. SEG-D- Format Conversion a CMUI internal format
2. Geometry Assignment
3. Tracing Edition
4. Amplitudes Recovery
   Correction by sphericaldicergence: $1/tv^2$
   Logarithmical Gain: 2 dB/s. 0 - 12 s.
5. Refraction Statics
   Offset range for modeling: 200-150 m
   V0 velocity = 1500 m/s
   Replacement Velocity = 3400 m/s
   Datum = 4000 m
6. Noise Attenuation (Despike)
7. Sort in CDP's
8. Gain: AGC 500 ms.
9. Surface Consistency De-convolution
   Type: Predictive
   Operator: 220 m.
   Prediction Distance: 24 m
10. Speed analysis. 1 km
11. Residual statics
12. Speed analysis. 1 km
13. Residual statics
14. Stacking
15. Filtering: 6/8 - 60/70
16. Gain: AGC 1000 m/s
17. FD Migration
18. Noise Attenuation: FX-Decon

Plotting Parameters

19. Filtering
20. Gain
21. Plotting

CONCLUSIONS

REFERENCES CITED IN THE ORIGINAL WORK

STRUCTURAL ADMISSIBLE SECTIONS IN THE SECTOR BETWEEN SUESCA AND SOGAMOSO, EASTERN CORDILLERA BASIN[1]

GEOSEARCH LTDA

Calle 29 No. 6-58, Of. 903

Tel.: 57-1-2323655 - Fax 57-1-2887993

Bogota D.C., Colombia

E-mail: geosearch@gmail.com

2009

INTRODUCTION

In this work, three structural admissible sections are presented in one sector of the Eastern Cordillera, between Suesca and Sogamoso cities, taking available geological information as a base, and completing it with interpretation of images or remote sensors data, geological cartography, and interpretation of seismic sections.

LOCATION

The study area is located inside the Eastern Cordillera Basin, in Cundinamarca, Boyaca, Santander, and Casanare departments, with an approximately extension of 1176699.278 ha (Figure 1).

[1] Consultoría para la elaboración de tres secciones estructurales admisibles en el sector comprendido entre Suesca y Sogamoso, Cuenca de la Cordillera Oriental. Geosearch Ltda.

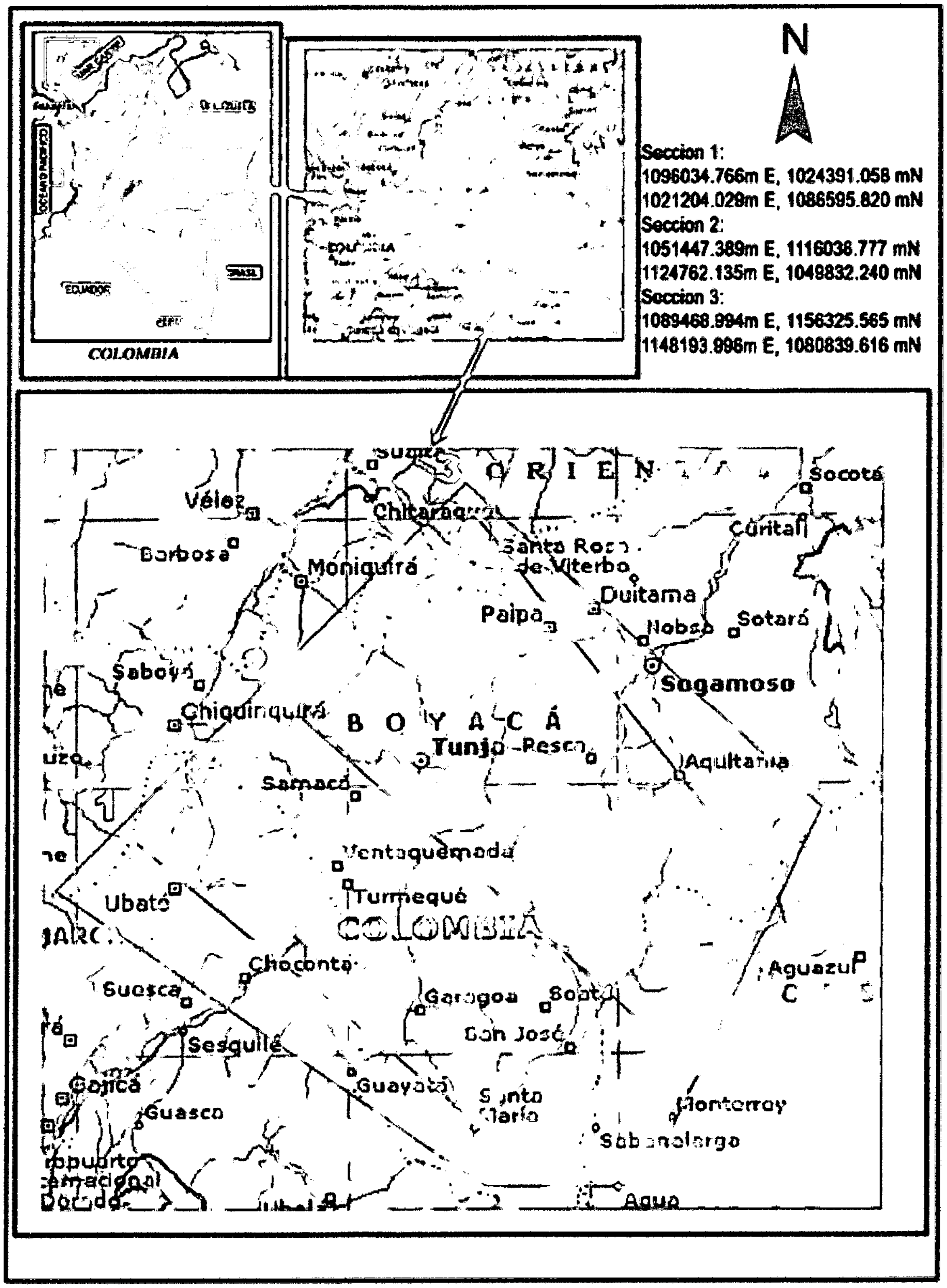


Figura 1. Location Map.

METHODOLOGY

In order to optimize the data acquisition, processing and to achieve quality results, the project was carried out in three phases:

1) Data Acquisition Stage

This phase consists in:

Preparation

- Compilation and analysis of the existent geological data of the study area: geological maps, stratigraphic columns and technical reports. Acquisition of topographic maps. The digital information of subsoil (seismic and borehole information) and technical reports, was supplied by the ANH.
- Preliminary interpretation of remote sensors' images.
- Determination of the cartographic control sectors (scale 1:25000).
- Formation and distribution of the working teams in the field.
- Preparation of the logistics and technical materials for the field work.

Field work

- Verification of the geological cartography and acquisition of new data lengthwise the transect 1 (Carmen de Carupa- San Luis de Gaceno), transect 2 (Sutamarchán- Urury) and transect 3 (Gámbita-Pajarito).
- Verification of the geological cartography, at scale 1:25000, has been executed in every single programmed transect.
- Stratigraphic sections survey. In areas, where there was no sufficient data about the thickness of some stratigraphic units, the measurement of thickness of some stratigraphic sections was carried out using GPS, and the representation of the litostratigraphic characteristics in generalized columns, at a scale 1:1000.

2.) Data Processing Stage

The data processing phase consisted in the integration of the preparation phase data with the data of the field work phase.

- *Analysis and processing of the field data.* The following was generated: field formats, photographic records, which illustrate the sectors of cartographic control, samples formats and graphics of the stratigraphic surveys and a preliminary description of the stratigraphy in the sectors of cartographic control.
- *Complete interpretation of remote sensors images* (satellite images from Radar, Spot and Landsat).
- *Seismic line and borehole information.* This data was aimed to represent the structural configuration from the surface until the level where the quality of the data would allow it. It would be focused on the definition of structures, which potentially contain hydrocarbons. Nevertheless, it was not the most appropriate, and the data volume that it would bring, would not be enough. As a result, it was not worth using this data for the elaboration of structural sectors.
- *Conclusions of the data processing stage.* Description of the stratigraphy in the sectors of cartographic control (generated during the analysis phase and processing the field data) and the complete interpretation of remote sensors images, allowed for showing numerous inconsistencies of cartographic, stratigraphic and structural type.

3) Delivered Products

- Advancement Reports
- Final Products
- Rock Samples

This information is available in EPIS-ANH.

STRATIGRAPHY PHYSICS (Attachments 1 and 2)

The integration of the information and the conclusions from cartographic work in this study gave as a result the stratigraphic succession shown in the Table 1. This stratigraphic succession corresponds to the Palaeozoic, Jurassic, Cretaceous, Paleogene and Neogene rocks and recent deposits (benches, fans, colluviums and alluviums).

BIOSTRATIGRAPHY

Relation among the identifications corresponded to the paleontological samples collected lengthwise along the transects in the sector comprised between Suesca and Sogamoso, Oriental Cordillera Basin.

1) Paleontological identifications by transect, station, formation and floor (Table 3).

2) Alphabetic list of different paleontological groups identified with their stratigraphic position (Table 4).

STRUCTURAL GEOLOGY

The structural geology consists in the structural analysis of the area and the generation of a structural evolution model based on the compiled, integrated and interpretive information, and on the new information brought to this project. The structural analysis consists in a description of the principal structures including location, geometry and orientation, in addition to the cinematic analysis, which is focused on the interpretation of the deformational movements responsible for the development of the structures. The model of the structural evolution is generated on a base of admissible structural sections, which were elaborated, showing the sequence of deformation in the time with three diagrams (pre-Cretaceous, Palaeogene and Neogene).

4 Analysis of compression vs. transpression and their relation with the geometry of the traps.

5 Discussion about the temporality of the deformation and its relation with the generation, migration and trapping of hydrocarbons.

6 Identification of areas of interest for the prospection of hydrocarbons based on the evaluation of the geological information compiled and generated in the present project.

6 PROSPECTIVE AREAS

7 CONCLUSIONS

REFERENCES CITED IN THE ORIGINAL WORK

INVENTORY, INTERPRETATION AND INTEGRAL EVALUATION OF THE GEOLOGICAL, GEOPHYSICAL AND GEOCHEMICAL INFORMATION OF SOÁPAGA BLOCK. PROSPECTIVITY REPORT[1]

National University of Colombia

Faculty of Sciences – Department of Geosciences

www.unal.edu.co

2008

SUMMARY

The Soápaga Block is located in the Eastern Cordillera Basin, in the vicinity of the Boyacá Department, Colombia - South America, and it corresponds to a polygon of 2272.3 km^2, which features a Cretacic succession affected by the Soápaga and Boyacá faults. These separate edges with several thickness of cretacic sediments are smaller than those of the eastern side of the Soápaga Fault, where the thickness of strata of the Upper Valanginiano to the Maastrichtiano only reaches 1500 m. This is a very advantageous geologic situation for the hydrocarbons exploration in cretaceous rocks, because the organic matter is not overmature as it occurs in other sectors of the Eastern Cordillera. The stratigraphic succession crossed in Bolívar-1 well indicates that petroleum is in the fractured cherts of the lower part of the Mid Guadalupe Formation and in the fine sands of the higher part of the Lower Guadalupe Formation.

[1] Inventario, interpretación y evaluación integral de la infomación geológica, geofísica y geoquímica del Bloque Soápaga. Informe de Prospectividad. 2008.

The most interesting stratigraphic objective is Une Formation, which is located approximately 1800 m below the surface. The main anticlines, in order of importance are: 1) La Chapa-La Cuche 2) Tasco 3) Socotá, and 4) Bisbita. Simple Bouguer, Total Bouguer and Residual Bouguer superposed anomalies infer the presence of a sedimentary sub-basin in the central sector of the block, in which southest end Bolívar-1 well is located. The evaluation of residual anomaly maps and Euler depth solutions coincide in determination of a sedimentary sub-basin of intermediate depth, with a sequence between 1200 m and 1500 m of depth, making very interesting the exploration toward the northeast of Bolívar-1 well, following the sub-basin elongation.

The seal is constituted by the shales and margas of the mid Guadalupe Formation and the source rocks by biomicrites and margas of Chipaque Formation.

Units featuring the best characteristics of potential reservoir are located in the Tertiary and they include the Picacho (Middle Eocene) and lower Socha (Upper Paleocene) formations. The structural traps linked to the folds of the underlying block of the Soápaga Fault are mainly expressed in the folds located to the western site of this block, and they comprise the Tasco anticlines to the south and The Chapa-The Cuche to the north. These folds are standing and they probably involve the basement.

The geochemical data from boreholes and outcropping indicate the presence of organic, humic-terrestrial matter of kerogen type III, for the whole tertiary sequence (Concentración, Upper Socha and Guaduas formations), and the presence of organic matter of marine origin of kerogen type II, for the sequence of cretaceous shales. Multiple manifestations of liquid hydrocarbons exist on the surface of the study area, in Tertiary and Cretaceous units, which indicates that the generating rocks reached conditions for generation of hydrocarbons. The hydrocarbons of Bolívar-1 well are low gravity hydrocarbons API (18°) in rocks corresponding to the Lower Guadalupe Formation. The data of maturity and the geochemical models suggest that shales of Chipaque and Mid Une formations would be in windows of early generation of hydrocarbons (% Ro 0.55-0.7) and the shales of Tibasosa Formation would be in window of mature generation (% Ro 0.7-1.3) in the deepest parts in the study area. The geochemical rock data and crude suggest the existence of an oil system with generating rock in Chipaque Formation, and reservoir rock Mid and Lower Guadalupe formations, and the possibility of oil systems in rocks of Lower Cretaceous such as Tibasosa - Une (?). This study defined four areas of interest with total volume of resources to prove with a conservative approach that corresponds to 18.8 MMSTB, an average estimate of 34 MMSTB, a median of 40.8 MMSTB and an optimistic approach of 54.7 MMSTB.

OBJECTIVE

To carry out the integral evaluation and the interpretation of geological, geophysical and geochemical data acquired by the Hydrocarbon National Agency (ANH) with respect to the Soápaga Block, generating a model of Soápaga Block for its further use by the companies interested in the area.

GENERAL DATA AND BACKGROUND INFORMATION

Geographic location

The study area corresponds to the Eastern Cordillera, located in the Colombian Andes to the northwest of South America, in the Boyacá Department, Soápaga Sector. With regard to the closer municipalities, it is approximately located at 48 km to the SE of Tunja and 200 km to NW of Bogotá. It bounds to the north with Susacón town, to the south with Firavitoba town, to the west with Duitama and Tibasosa towns, and to the east with Jericó town and the Pisba Moorland. Figure 1 represents the study area and corresponds to a polygon covering an area of 2777.85 km^2.

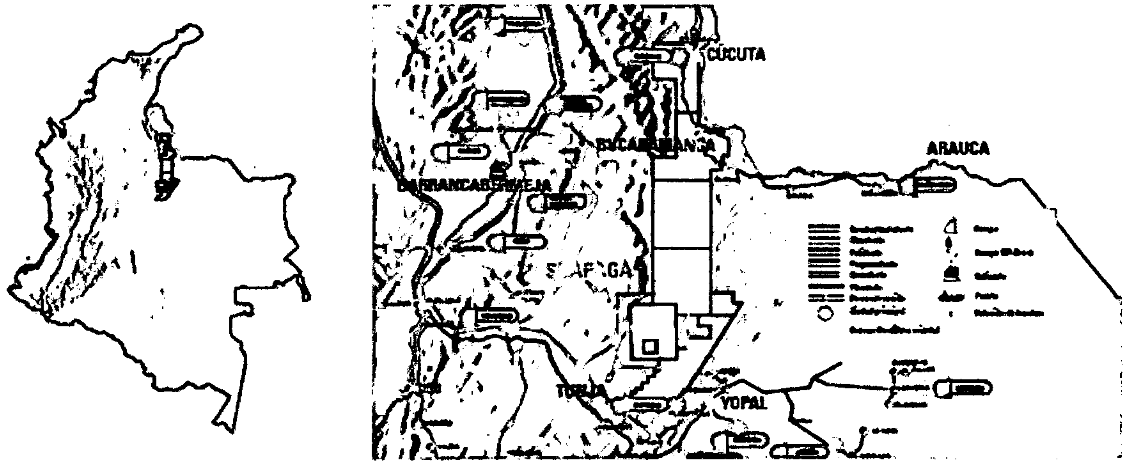


Figure 1. Map of location of Soápaga Block in the Boyacá Department, in the political division of the Colombian Territory.

Backgrounds of structural geology

Big structures are seen in the region shown in Figure 2. From west to east are the following: The north continuation of the eastern flank of Arcabuco Anticline, formed by rocks of Montebel and La Rusia formations; the La Floresta Anticline, delimited in western and eastern flanks by two important faults, guided SSW-NNE, corresponding to Boyacá and Soápaga faults, respectively; the Paz del Río Syncline, delimited to the west by the Soápaga Fault and to the east by the western flank of the Cravo Sur Anticline, characterized for featuring synclinal an anticlinal narrow folds of short extension; the north continuation of Farallones de Medina Anticline, conformed by rocks of principles of Cretaceous and characterized for presenting relatively symmetrical and extensive structures, with their axes oriented NE-SW and with dextral displacement in faults.

Most of the study area presents a compressional structural style, showing structures such as folds and faults of regional extension. These structures are probably related to each other (Ulloa et al. 2003).

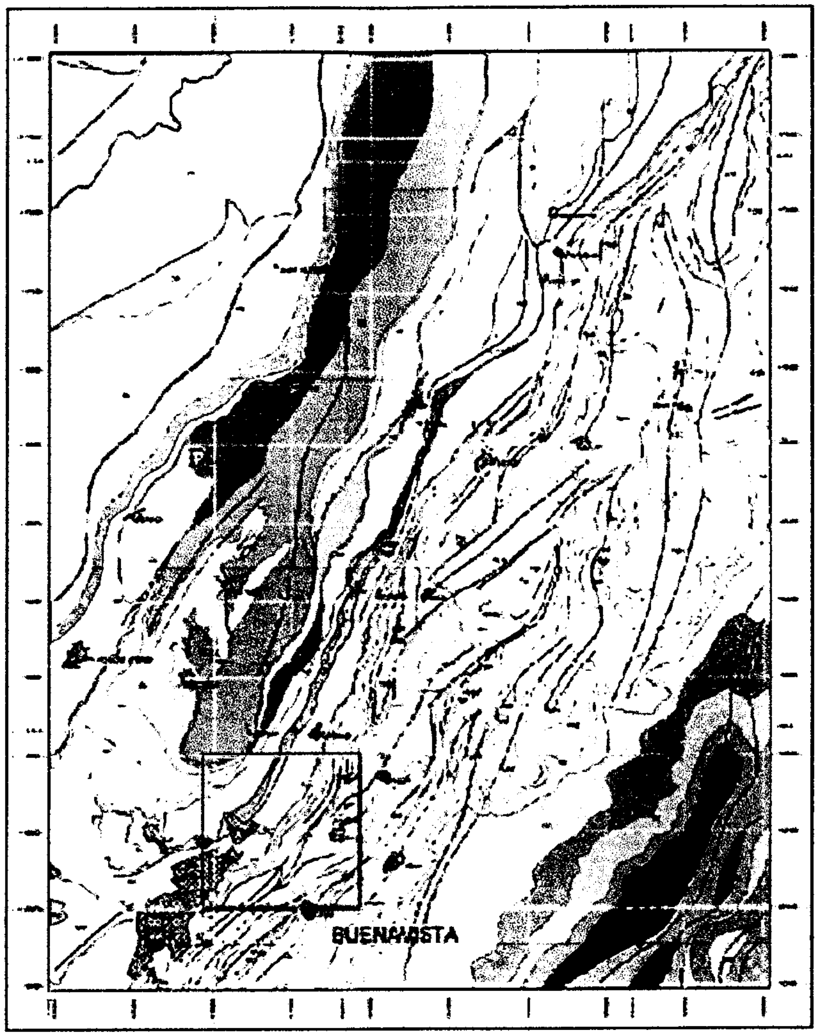


Figure 2. Geologic Map – structure of the area.

Geochemistry background data

In the study area the available geochemical data has been obtained mainly from outcropping samples and seepages. Different types of analysis were applied, including pyrolysis Rock-Eval, gas chromatography with masses spectrometry, and carbon isotopes (Cities Services, 1983, Mello. Et al.1995, and Corelab, 1997). In total, geochemical analysis has been made to 189 samples obtained in field in the study area and in its surroundings. As for information of wells in the area, only two have been perforated: Corrales-1 and Bolívar-1, of which the only hydrocarbons producing well is Bolívar-1. In both wells geochemical analysis of drilled rocks has been made. However, the stratigraphy found in these two wells is not similar as in

Corrales-1 well, the cretaceous sequence was not drilled, while in Bolívar-1 well, cretaceous sediments were drilled.

Tectonic Framework

The Soápaga Block presents a metamorphic basement, and units of the Upper Paleozoic along the Floresta Massif as its main characteristics. This massif tops in a periclinal closure toward the cross-sectional valley that links Duitama and Sogamoso cities, which is drained by River Chicamocha. The Floresta Massif is separated to the west by the Duitama-Belen Depression from the Arcabuco Anticline, and to the east by the River Chicamocha Valley from the Pisba High.

Due to its SW-NE structure and its folding style, the Floresta Massif belongs to the intermediate segment of the Eastern Cordillera. However, the faults that affect the eastern flanks of Arcabuco and Floresta anticlines rotate some kilometers away to the north toward a NNW-SSE direction, which corresponds to the Bucaramanga Fault, and it determines the structural train of the santander Massif.

Regional analysis

The Floresta Massif is integrated to the metamorphic basement of the North Andean Block. Before the Upper Devonian, the area of the future mountain range was subject of regional erosion, and during the Upper Devonian to a rupture event of first order. During the cretaceous development the area of the Floresta Massif formed a topographic high. The Boyacá and Soápaga faults make part of the south ending of the Bucaramanga Fault. The Soápaga intra-mountain Basin receives detritus contributions from the Santander Massif since the Paleocene.

Structural Geology

The Soápaga Fault divides the block in two parts. The western area exhibits basement tectonics controlled by inherited faults from the Upper Paleozoic and of Lower Jurassic. The eastern part is affected by faults and folds of the Tertiary, which reflect, as a group, different phases in the Andean evolution.

Structural sections

Eight structural sections were obtained, the location of which is shown in Figure 3. This information is available in EPIS-ANH.

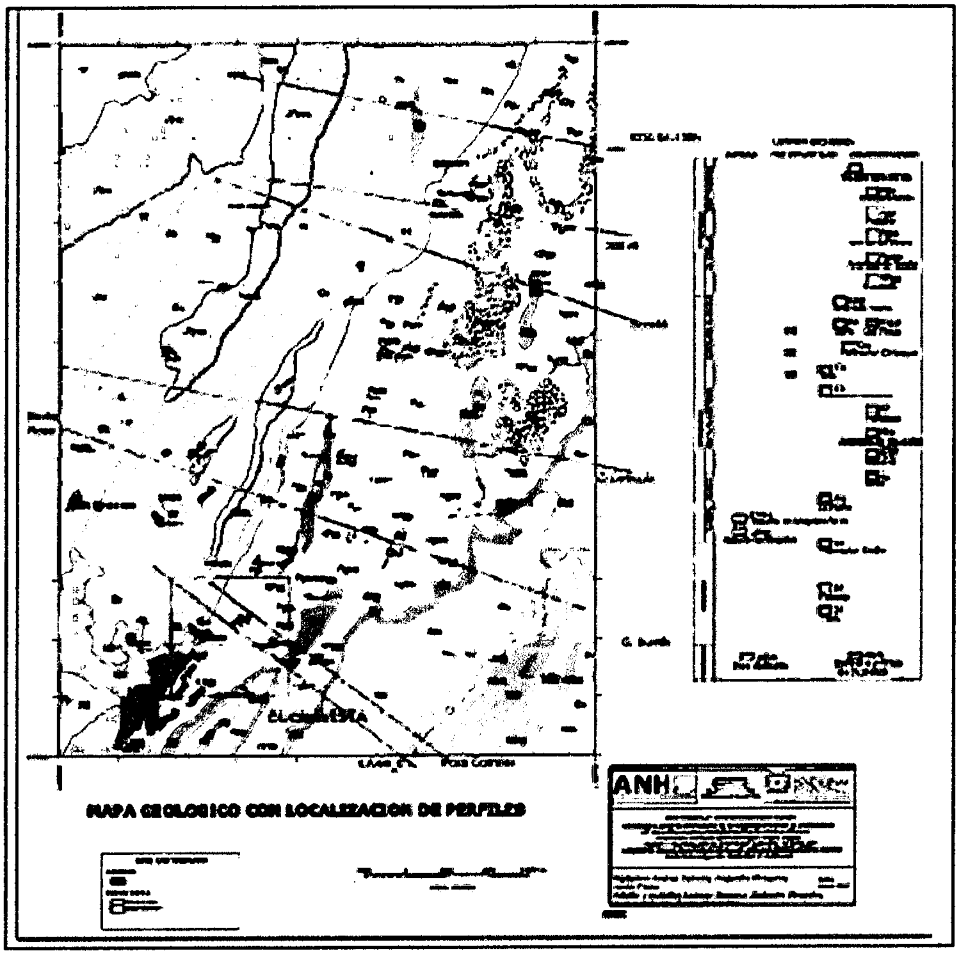


Figure 3. Geologic map of the block with the location of the structural profiles surveyed for this report. Base: Maps of the Geologic Atlas 1:100000 of INGEOMINAS, and not published cartographies by A. Kammer.

For each section, the surface data was independently evaluated (geologic limits, dipping data) to determine the thickness and slopes of the units. With this procedure it was possible to define variations of thickness among certain reference points from the block to the east of the Soápaga Fault.

As for the initial geometry of the units of the restored block, an increase of the thickness of the cretaceous formations is observed toward the east for the sections of the southern domain of the Floresta Massif. As a preliminary appreciation, it is proposed that the units be clustered even more toward the axis of the Arcabuco-

Guantiva Anticline, reaching minimum thickness in the area of Bisagra of this regional structure. The reduction rates vary around 10%, being increased toward the contiguous folds to the Soápaga Fault.

Potential Methods

The following is a description of the compilation of works, processing and interpretation of gravimetric data in Soápaga Block and surrounding areas that are available in the database of the Gravimetric Map of Colombia (Esquivel et al., 1998). The processing of data has consisted in the realization of maps of the information fields by means of the Geosoft Oasis Montaj software.

The ground digital model

Starting from the geo-referenced values of heights of gravimetric stations, a process of linear interpolation was carried out, obtaining a digital model of the terrain (Figure 4). Interpolated heights vary between 626 m and 3926 m. A northeast tendency is observed in the intercalated distribution of highs and topographical low-lying areas, delimitating heights and elongated depressions. The digital model of the terrain allows to infer a continuity in the geological formations with northeast-southwest direction and a bigger alternation of litological units in northwest-southeast direction. Based on the topographical information, it is fundamental to establish corrections because of the gravimetric anomalies.

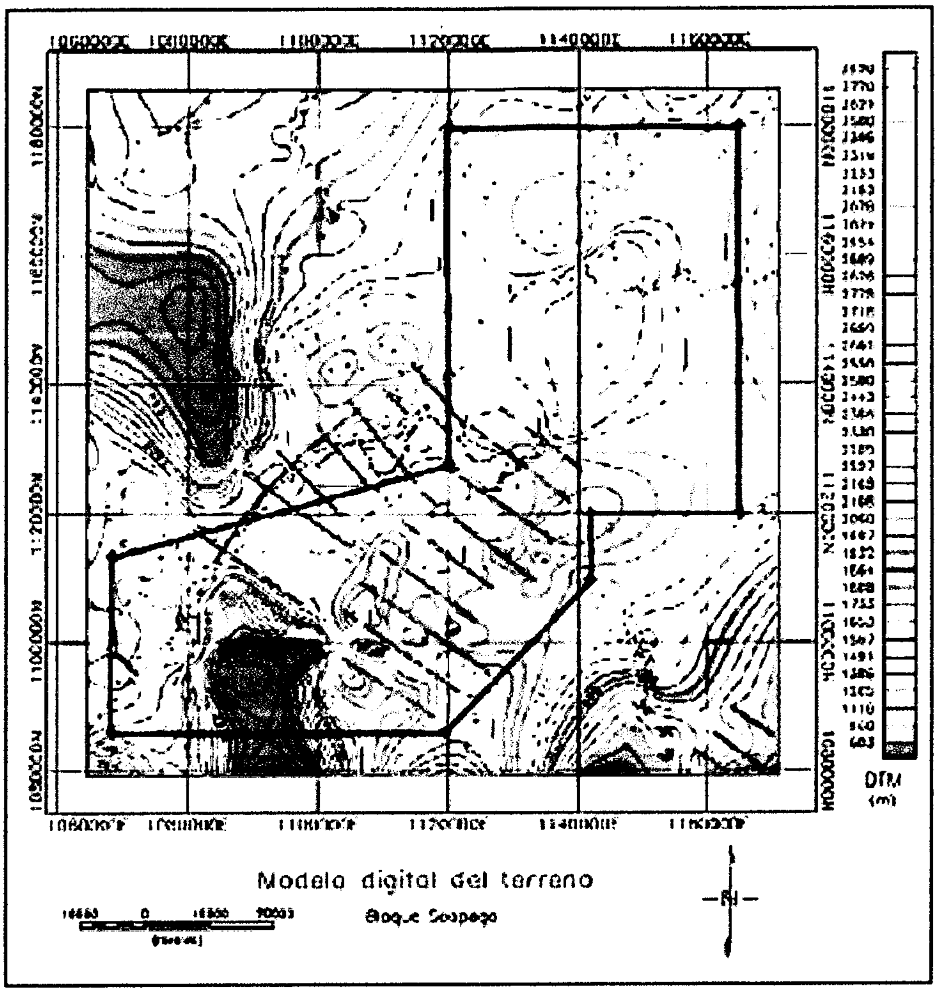


Figure 4. Map of the digital model of the terrain.

Map of Total Bouguer Anomaly

Starting from the geo-referenced values of total Bouguer Anomaly, a process of linear interpolation was done, obtaining the map of total Bouguer anomalies, represented by means of scale of colors (Figure 5), with a range of values between -138 mGals and -42 mGals. On this map, the simple Bouguer anomalies are conserved, with a smaller definition in the central part of the Soápaga Block, inferring the presence of low density rocks associated with the presence of sedimentary sub-basins inside the study area. Another sub-basin is also seen in the northwestern sector of Soápaga Block. These anomalies maintain the northeast-southeast orientation. The alignment of specific solutions is highlighted in the west end of Soápaga Block, which has been interpreted as the gravimetric response of geologic faults with northeast-southeast orientation - whose continuity on the vertical reaches several thousands of meters. With regard to the sub-basin identified in the Bouguer anomalies, the solutions of depth indicate the presence of a very near body to surface, in the first thousands meters. This allows to interpret that the geometry of the basin is controlled more by the structural aspects, limiting it in the sectors to the east and west of the basin, than by variations in the geometry that could be associated with a simple basin without a structural control. However, due to the lower number of gravimetric stations, the modeling of depth has been done with, it was not possible to determine the variations of depth inside the same sub-basin.

Stratigraphic Evaluation

The area of Soápaga reveals a cretaceous succession deposited in a paleohigh close to the eastern border of the Cretaceous Colombian Basin. The thickness of its units are comparatively reduced with regard to those of the axis of the basin that today outcrop in most parts of the Eastern Cordillera. The area of Soápaga is in extremely eastern position within the cordillera, and it exposes proximal strata that were deposited on a basement block that had smaller subsidence than adjacent blocks. The Soápaga and Boyacá faults separate stripes with cretaceous sediments of different thickness, being smaller those of the eastern side of the Soápaga Fault. In the study area the thickness of strata of the Upper Valanginian to the Maastrichtian reaches only 1500 m. This is a very advantageous geologic situation for the hydrocarbons exploration in cretaceous rocks because the organic matter is not overmature as it occurs with other sectors of the Eastern Cordillera, that have cretaceous thickness from 4 to 5 km together with others from 3 to 4 km of tertiary sediments. The smallest subsidence in the block was also kept for the Tertiary, the thickness of it is smaller than those in other areas. In the area of Soápaga the Paleocen to Oligocen only reach 2000 m of thickness.

Physical Stratigraphy

The stratigraphic units, which outcrop in the study area, correspond to igneous, metamorphic, and sedimentary rocks, with ages since Precambric till the Cuaternary. In Figure 5 we can see the generalized column of the Soápaga area that summarizes the stratigraphy of the area. Table 1 includes a description of the units contained in the area, ages, composition, lito-stratigraphic and alo-stratigraphic units, sedimentary environments and tectonic framework.

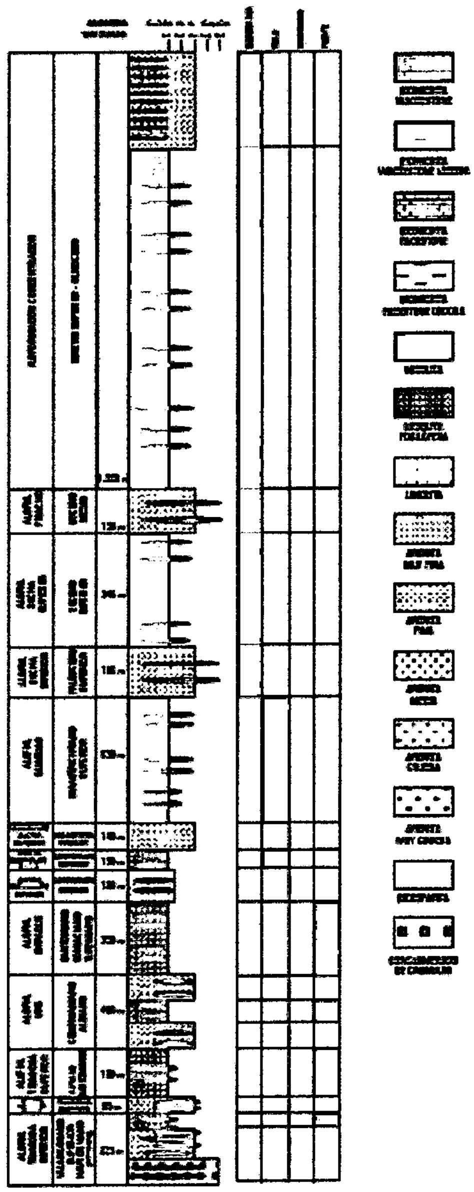


Figure 5. General stratigraphic column of Soápaga Block.

Table 1. Stratigraphy of the underlying block (eastern) of the Soápaga Fault.

[illegible] ESTRATIGRAFICA	[illegible] / FORMACION	ESPESOR EN METROS	ESPESORES TOMADOS DE POZOS CORRALES Y BOLIVAR	ESPESOR [illegible]	ESPESOR [illegible]	[illegible] AMBIENTE DE DEPOSITO	[illegible] FUENTE DE [illegible]	ESTADO [illegible] DE LA MATERIA ORGANICA
Oligoceno Superior	Concentración Superior	1.350	C173 (Parcial)			Arenitas con intercalaciones menores de lodolitas		
Oligoceno Medio - Eoceno Superior	Concentración Inferior		527			Lodolitas con intercalaciones menores de arenitas		Inmaduro
Eoceno Medio	Picacho	130	248			Arenitas y conglomerados fluviales	Reservorio	Inmaduro
Eoceno Inferior	Socha Superior	340	185			Lodolitas con intercalaciones menores de arenitas		Inmaduro
Paleoceno Superior	Socha Inferior	150	210			Arenitas y conglomerados fluviales	Reservorio	Inmaduro
Maastrichtiano Superior	Guaduas	302	B450 - C257 (Parcial)	185 (Parcial)		Lodolitas con intercalaciones menores de arenitas. Capas de carbón en la parte inferior. Ambiente costanero		Inmaduro
	Espesor total del Maastrichtiano Superior al Oligoceno:	2.312						
Maastrichtiano Inferior	Guadalupe Superior	140	140	172	112 (Parcial)	Arenitas de frente de playa y llanura costera	Reservorio	Submaduro
Campaniano Superior	Guadalupe Medio	130	130	304	131	Lodolitas y biomicritas de offshore	Roca fuente	Submaduro
Campaniano Inferior	Guadalupe Inferior	150	150	150	130	Lodolitas y biomicritas parcialmente silicificadas de frente de playa inferior		Submaduro
Santoniano - Coniaciano - Turoniano	Chipaque	330	68 (Parcial)	181 (Parcial)	337 (Parcial)	Lodolitas y biomicritas de offshore	Roca fuente	Maduro
Cenomaniano	Une Superior	400			113	Biosparitas / arenitas de frente de playa y llanura costera	Reservorio	Maduro
Albiano Medio Y Superior	Une Medio				136	Lodolitas, margas y biomicritas estuarinas y de offshore	Roca fuente	Maduro
Albiano Temprano	Une Inferior				152	Biosparitas / arenitas de frente de playa y llanura costera	Reservorio	Maduro
Aptiano - Barremiano	Fm. Tibasosa Superior	190			117 (Parcial)	Lodolitas, margas y biomicritas estuarinas y de offshore	Roca fuente	Maduro
Hauteriviano Superior	Fm. Tibasosa Medio	90				Arenitas / biosparitas de frente de playa y llanura costera	Reservorio	Maduro
Valanginiano Superior y Hauteriviano Inf	Fm. Tibasosa Inferior	223				Conglomerados y arenitas fluviales en la base, seguidas de arenitas / biosparitas de frente de playa, cubiertas por lodolitas, margas y biomicritas de offshore		Maduro
	Espesor total del Valanginiano Superior al Maastrichtiano Inferior:	1.583						

Organic Geochemistry of Soápaga Block

1D Modeling in Soápaga Area

Geochemical data from Corrales-1 and Bolívar-1 wells were used to generate 1D models of hydrocarbons generation, gauged with the data of maturity (Ro and/or Tmax) obtained from ditch samples. This model shows the most possible scenario of generation for the deposit to the east of the Floresta Massif. This suggests that the rocks of the Lower Cretaceous (Tibasosa Formation) could enter into the window of hydrocarbons generation at the end of Cretaceous, during a period of great subsidence, related with the deposit of Guaduas Formation. From that time until about 23 million years ago this deposit continued subsiding, reaching the sedimentary sequence, and the sequence of Cretaceous rocks would reach its highest grade of thermal maturity, being most of this sequence in early generating window, and Tibasosa Formation in a late stage of maturity for liquid hydrocarbons. However, the detention in the creation of space to accommodate sediments from the deposit of the Concentración Formation, makes that since that time the grade of maturity of rocks is the same, resulting in stagnation of the rate of transformation of organic matter. As a result of this, the transformation values do not continue to increase, reaching maximum values of 7% in the lower part of Tibasosa Formation and gradually reducing down to almost zero in the Chipaque Formation. This indicates that a very small fraction of organic matter could have been turned into hydrocarbon to be expelled, and stored in the structures present in the area.

Seismic Processing

A revision and generation of prestack, migrated in time data, were carried out. In order to do this, different groups of seismic data (2D) were taken through a consistent processing, which allowed a better visualization of structures such as the Soápaga Fault, which has a north-south orientation. The 2D seismic lines were registered with east-west orientation with regard to the Soápaga Fault, except for one of them, that was registered in north-south direction, following the orientation of the system of faults. The initital tests and the sequence of applied processing allowed the appropriate treatment of effects close to the surface, due to variations in elevations in the study area, and to the meteorited layer, permitting also to generate final migrations to a uniform datum of 4000 m.

The processing included the following routines: spherical divergence corrections, surface consistent amplitude corrections, edition of spikes and burst type noise, deconvolution, refraction statics, residual statics, pre-stack migration in time, f-x deconvolution, section of pre-stacking in time, taken to the final datum of 4000 m, tests of pass-band filtering for visualization, final stacking. Figures 6, 7 and 8 show the results of PSTM sections with its respective velocities field for the ANH-SP-2005-22 line, generated from the sequence of the proposed processing.

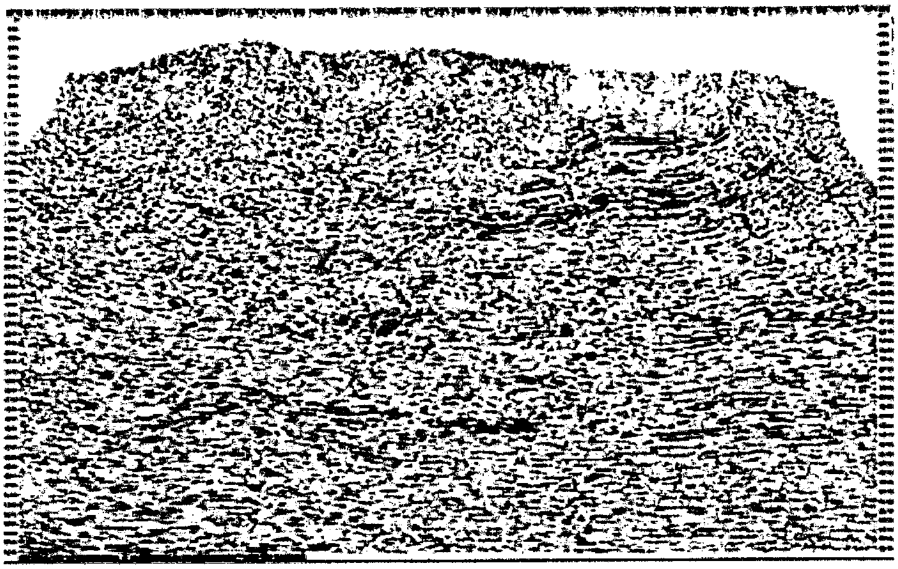


Figure 6. PSTM line ANH-SP-2005-22.

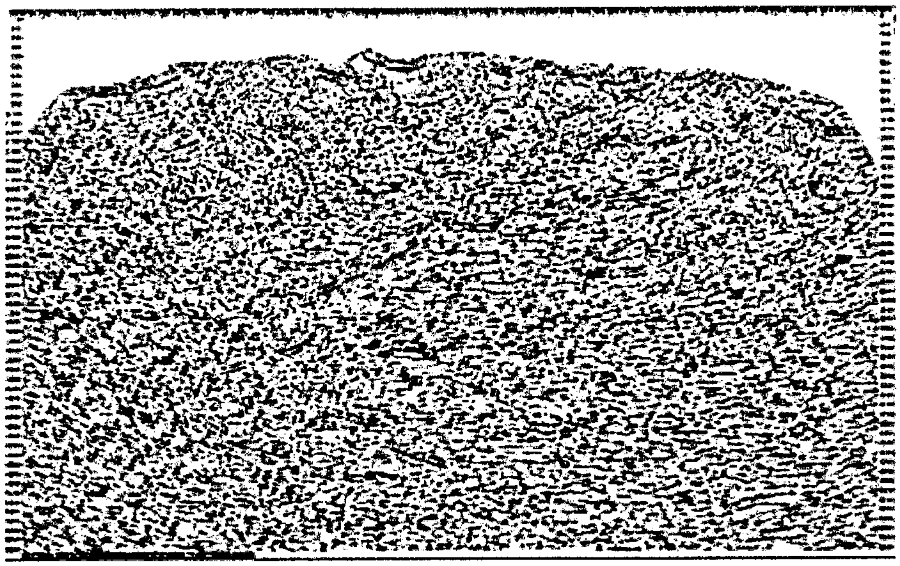


Figure 7. Post-stack migration of Initial Processing ANH-SP-2005-22.

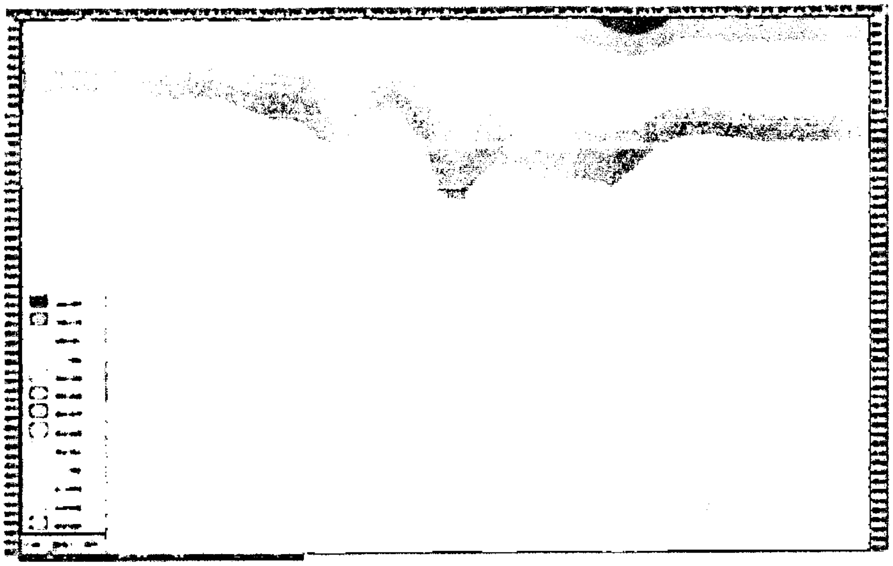


Figure 8. Velocities field PSTM - Line ANH-SP-2005-22.

Resources Evaluation

The records of Bolívar-1 and Corrales-1 wells were interpreted, and the petrophysical characteristics of the formations of interest in the Soápaga Block were evaluated, in order to use them as analogs for interpretation of porosity of potential reservoirs in other areas of the Block.

Results of records evaluation

The following results were obtained for different levels of interest, including the areas already proven, in just two existing wells in the area. The summarized values were used as analogs for the evaluation of resources, keeping in mind that no values of pertrophysical properties exist at all in any other part of the block and that, therefore, these are the closest approximation of the properties of the formation. However, a high level of uncertainty exists considering their specific character. Figure 9 shows the intervals evaluated for the Corrales-1 and Bolívar-1 wells, the results of which are seen in Table 2.

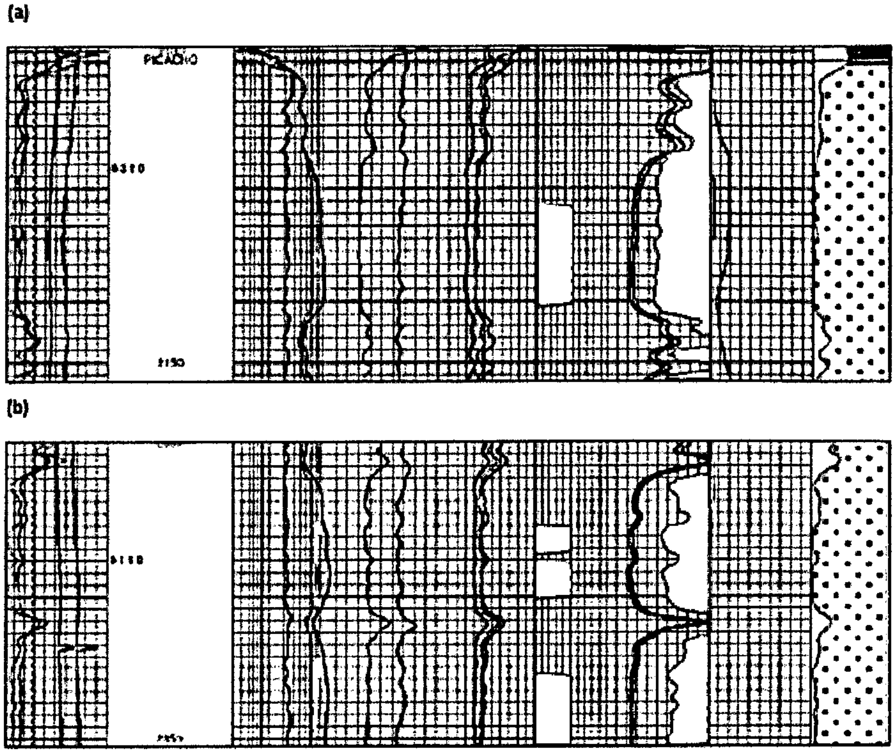


Figure 9. Corrales-1 intervals evaluated: a) 2125-2141 b) 2314-2325 and 2340-2350.

Table 2. Pessimistic values of petrophysical properties in intervals of interest for each well (maximal saturations).

PROPIEDADES PETROFISICAS INTERVALOS EVALUADOS						
POZO	FORMACION	INTERVALO (ft)	LITOLOGIA	Vshl	PHIe	Sw
CORRALES-1 (ver anexo petrofísica Corrales-1)	Picacho	2125-2141	Sandstone	0.770548	0.016	0.492
	Picacho	2314-2325	Sandstone	0.603170	0.090	0.077
	Picacho	2340-2350	Sandstone	0.837330	0.054	0.030
	Picacho	2430-2440	Sandstone	0	0.043	0.003
PROPIEDADES PETROFISICAS ZONAS DE INTERES						
POZO	FORMACION	INTERVALO (ft)	LITOLOGIA	Vshl	PHIe	Sw
BOLIVAR-1 (ver anexo petrofísica pozo Bolívar-1)	Guadalupe Superior	1750-1780	Sandstone	0.010	0.1237	C0.850
	Guadalupe Superior	1818-1838	Sandstone	0.008	0.1165	0.84843
	Guadalupe Medio	2230-2838	Dark Chert	0.5347	0.0493	0.850
	Guadalupe Inferior	2854-2868	Sandstone	0.1399	0..0794	0.531832
	Guadalupe Inferior	2630-2890	Sandstone	0.5093	0.0738	0.603434 0.850
	Chipaque	3800-	Lime Mudstone	0.4775	0.0374	

Definition of Areas with Exploratory Interest

Geology of petroleum

Kerogen type and accumulations of hydrocarbons

The geochemical data of wells and outcropping indicate the presence of organic humica-terrestrial matter of type III kerogen for the whole tertiary sequence (Concentracion, Upper Socha and Guaduas formations), and the presence of organic matter of marine origin of type II kerogen for the sequence of cretaceous shales (Chipaque, Middle Une and Tibasosa formations). There are numerous manifestations of liquid hydrocarbons on the surface of the study area, in Tertiary and Cretaceous units, which indicates that generating rocks reached conditions of generation of hydrocarbons in the area of Soápaga. Until this time, just one accumulation in the area has been found, corresponding to Bolívar-1 well, which found low-gravity hydrocarbons of API (18°) in rocks corresponding to Lower Guadalupe Formation.

Maturity of source rocks

Data of maturity of wells and outcropping show that fine granulated rocks of tertiary sequence in the study area are immature, and that maturity is increased with the stratigraphic position, that is to say that rocks of Upper Cretaceous (Pinos and Chipaque) are more mature than in tertiary rocks; nevertheless, they are more immature than the rocks of the Lower Cretaceous (Middle Une and Tibasosa). Additionally, the data of maturity and the geochemical models indicate that rocks enter into the generating window around 6500 feet deep in the deepest areas in the zone. There is no evidence of over-maturity of the organic matter in the available information. However, the existence of crude with low gravity API (<20°), as the one found so-far in Bolívar-1 well, suggests that the generated hydrocarbon could have been generated in an early stage of maturity of the source rock or in a late stage of maturity, but it could have been biodegraded in the reservoir.

Oil systems

In the study area, the reservoir rocks in the tertiary sequence correspond to fluvial origin sandstone successions intercalated with continental lodolites that belong to the Picacho and Lower Socha formations. As potential seals for tertiary reservoirs, there exists the Concentracion Formation composed by reddish to brownish exhumation of stratigraphically older units toward the east of the block. Starting with the integration of seismic, stratigraphic, structural information, the geochemistry and petrophysics of the Soápaga Block, a geologic model was defined, which consider that hydrocarbons in commercial quantities can be found. Starting from this geologic model, four structures of interest have been determined (plays) inside the block (Figure 10).

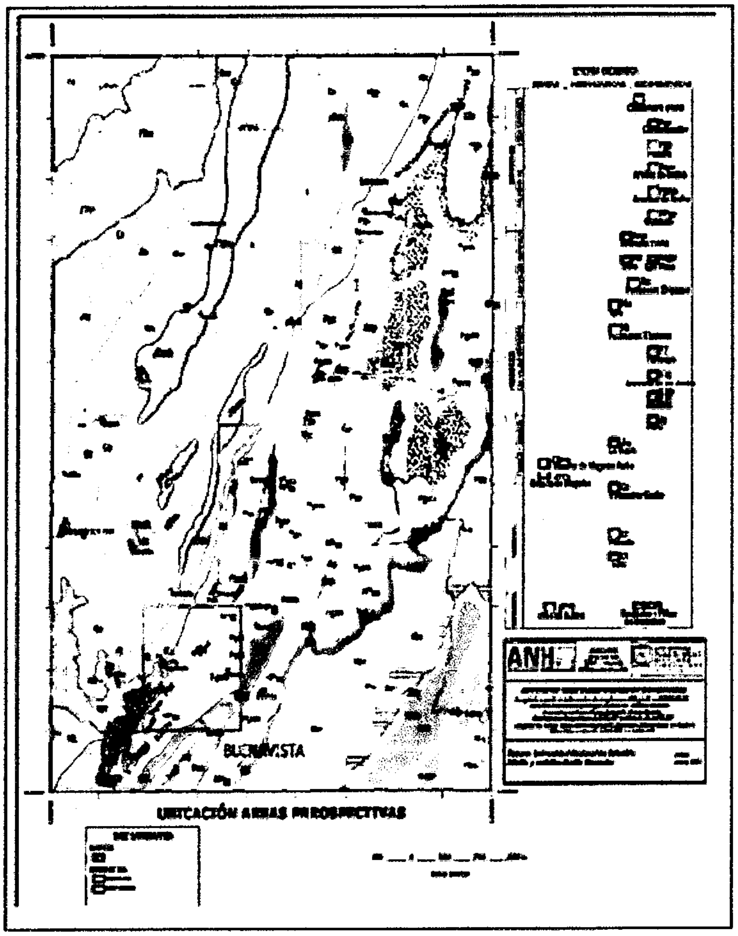


Figure 10. Location of structures of interest in Soápaga Block.

Evaluation of resources

For the calculation of resources (Table 3) for each one of the four estimated plays, the porosity values, shale volume, and saturation of water existing in intervals were taken into account in the only existing producing well in the area (Bolívar-1).

In order to know the median and an average value in the interval of interest, maximum and minimum values were used.

Table 3. Calculation of resources in Soápaga Block.

PLAY 1 FORMACION [illegible]		AREA: CONSERVADORA	AVE	NORTE MEDIAN	OPTIMISTA
	RESORCES (MMSTB)	3.068563021	11.124485	10.62006582	7.477651839
	AREA (ACRES)	1759	1759	1759	1759
	THICKNESS (FEET)	231	231	231	231
	PHIE (%)	10.71%	7.48%	8.84%	2.60%
	SW (%)	65.00%	74.04%	72.74%	49.78%
	BO	1.1	1.1	1.1	1.1
	FR	0.2	0.2	0.2	0.2
PLAY 1 FORMACION [illegible]		**AREA: CONSERVADORA**	**AVE**	**SUR MEDIAN**	**OPTIMISTA**
	RESORCES (MMSTB)	1.514220237	5.4885128	5.270223521	3.690955783
	AREA (ACRES)	863	869	868	863
	THICKNESS (FEET)	231	231	231	231
	PHIE (%)	10.71%	7.48%	8.84%	2.60%
	SW (%)	65.00%	74.04%	72.74%	49.78%
	BO	1.1	1.1	1.1	1.1
	FR	0.2	0.2	0.2	0.2
PLAY 2 FORMACION [illegible]		**CONSERVADORA**	**AVE**	**MEDIAN**	**OPTIMISTA**
	RESORCES (MMSTB)	1.115281238	2.94883083	4.123242904	7.335873171
	AREA (ACRES)	1358	1358	1358	1358
	THICKNESS (FEET)	120	120	120	120
	PHIE (%)	8.00%	8.24%	8.28%	7.52%
	SW (%)	85.00%	85.57%	78.53%	60.67%
	BO	1.02	1.02	1.02	1.02
	FR	0.2	0.2	0.2	0.2
PLAY 2 FORMACION [illegible]		**AREA: CONSERVADORA**	**AVE**	**SUR MEDIAN**	**OPTIMISTA**
	RESORCES (MMSTB)	0.380805023	0.85355183	1.355342837	2.373372082
	AREA (ACRES)	839	839	839	839
	THICKNESS (FEET)	89	89	89	89
	PHIE (%)	9.00%	8.24%	8.28%	7.52%
	SW (%)	65.00%	85.57%	78.53%	60.67%
	BO	1.02	1.02	1.02	1.02
	FR	0.2	0.2	0.2	0.2
PLAY 1 FORMACION [illegible]		**CONSERVADORA**	**AVE**	**MEDIAN**	**OPTIMISTA**
	RESORCES (MMSTB)	8.091813532	3.35806391	4.770213247	8.354620462
	AREA (ACRES)	2249	2249	2249	2249
	THICKNESS (FEET)	89	89	89	89
	PHIE (%)	9.00%	8.24%	8.28%	7.52%
	SW (%)	65.00%	85.57%	78.53%	60.67%
	BO	1.1	1.1	1.1	1.1
	FR	0.2	0.2	0.2	0.2
PLAY 3 FORMACION [illegible]		**CONSERVADORA**	**AVE**	**MEDIAN**	**OPTIMISTA**
	RESORCES (MMSTB)	3.332328473	8.85721046	12.5833108	22.05007448
	AREA (ACRES)	3913	3913	3913	3913
	THICKNESS (FEET)	135	135	135	135
	PHIE (%)	9.00%	8.24%	8.28%	7.52%
	SW (%)	95.00%	85.57%	78.53%	60.67%
	BO	1.1	1.1	1.1	1.1
	FR	0.2	0.2	0.2	0.2
PLAY 4 FORMACION [illegible]		**CONSERVADORA**	**AVE**	**MEDIAN**	**OPTIMISTA**
	RESORCES (MMSTB)	0.51831414	1.38415670	1.936951834	3.398075972
	AREA (ACRES)	452	452	452	452
	THICKNESS (FEET)	180	180	180	180
	PHIE (%)	9.00%	8.24%	8.28%	7.52%
	SW (%)	95.00%	85.57%	78.53%	60.67%
	BO	1.1	1.1	1.1	1.1
	FR	0.2	0.2	0.2	0.2
TOTAL RECURSOS (MMSTB)		10.61920037	34.[illegible]	[illegible]	54.7605927

CONCLUSIONS AND RECOMENDATIONS

- The analysis of the available gravimetric data of the Soápaga Block and surrounding areas allows for identification of the presence of superimposed negative simple, total and residual Bouguer anomalies that infer the presence of a sedimentary sub-basin in the central sector of Soápaga Block and in whose southern side the Bolívar-1 well is located.
- The evaluation of maps of residual anomaly and Euler solution of depth coincide in determining a sedimentary sub-basin of intermediate depth, with a sequence between 1200 m and 1500 m of depth, which makes it very interesting for exploring toward the northeast of Bolívar-1 well following the elongation of the sub-basin.
- The distribution of narrow edges (of specific depth solutions) in the sectors toward the west and east of the Soápaga Block infers the presence of structural features of high diving angle. However, based upon only this information it is not possible to determine the dip slope.
- There are some problems of stratigraphic terminology, since in some works it is considered that La Luna Formation is a hydrocarbon generator, while in other cases some formations like Churuvita and Conejo are mentioned, although all are temporary of the Chipaque Formation in the area of Soápaga. It is important to clarify this issue, in order to identify the presence of one or more oil systems in the area, because these units correspond to formations formally defined in the Middle Magdalena Valley and the western area of the Boyacá department (Arcabuco and Villa de Leiva areas) but not in the Soápaga area.
- In previous works, there was an attempt to define how many families of hydrocarbons can exist in the area; however, the available information does not allow to conclude it precisely, which implies that just one family is considered for some works (Corelab, 1997), in that of Petrobras (Mello, 1995) two families are mentioned and in that of Cities Services (1983) the possibility of three families is mentioned.

- The absence of detailed stratigraphic columns in the points where samplings were taken, specifically for the case of rock samples, does not allow to establish a good relationship between the properties of quality and maturity of the generating rock and the facial variations of the generating rocks, and their eventual relationship with variations in crude, as it is outlined in the study of Cities Services (1983).
- The mentioned above, along with the lack of data of the subsoil, prevent elaboration of reliable maps of good quality and maturity.
- The crudes found so far in the Soápaga Area are heavy (API gravity <20°), with indications of biodegradation, from a rock deposited in a maritime carbonic environment, and in an early stage of thermal maturity, which coincides with the deposit conditions and maturity of cretaceous rocks existing in the area.
- The rocks containing the highest potential of generating hydrocarbons in the basin, according to the realized studies, would mainly correspond to shales and biomicritas of Chipaque (Temporary equivalent of Churuvita and Conejo formations), and Tibasosa formations, although there are no many analyzed samples from this formation.
- The grade of maturity, according to the data of Tmax and vitrinite reflectance (%Ro) obtained from samples, indicates that the drilled sedimentary sequence in Corrales-1 and Bolívar-1 wells is essentially immature.
- The study carried out by Corelab (1997) suggests that seepages of Soápaga Block and the oils from Corrales-1 and Bolívar-1 wells were generated from rocks of La Luna Formation, at a maturity range between 0.75 and 0.8% Ro. However, equivalent rocks, corresponding to Chipaque Formation, do not reach these values in wells, and the rocks reaching similar values, according to generation 1D models, would be those of the Tibasosa Formation, which leaves the possibility that this formation is the main source of hydrocarbons in the area.
- The written above seems to contradict the theories of Mello et al. (1995) about the origin of the crude found in Bolívar-1 well, since these authors show good

correlation among the extracts of rock of Conejo Formation (Formation of Chipaque) and the crude found in the well. Although it is not possible to exclude the fact that facies of Chipaque and Tibasosa Formations are similarconsidering the marine environments where they were deposited.

- The Soápaga Block presents four areas of interest considered in this study. The total volume of resources, by a conservative approach corresponds to 18.8 MMSTB, an average estimate of 34 MMSTB, a median of 40.8 MMSTB, and an optimistic estimate of resources of 54.7 MMSTB.
- The complexity of the block at structural level makes it quite difficult to have an appreciation free of uncertainty with respect to results of resources, especially for Une Formation that is projected as a productive horizon of remarkable interest, and where the existing petrophysical information is obtained based only on outcropping samples.
- Considering the separation between the different seismic lines, and the fact that some plays were defined with one single seismic line and with the surface geology, the value of proven resources should be considered rather uncertain.
- Therefore, for any of the four plays above, the need of acquiring seismic information to detail and to determine the limits of traps is considered as a future action.

REFERENCES CITED IN THE ORIGINAL WORK

Cities Services (1983), Boyacá Área Geochemical Reports.

CORE LABORATORIES (1997). Geochemical Evaluation of one hundred twenty-two outcrop and seep samples. Soápaga Block, Eastern Cordillera, Colombia.

Esquivel, H.; Flórez, J.; Martínez, W.; Obando, G. and Sánchez, L (1998). Mapa Gravimétrico de Colombia, Convenio: IGAC - INGEOMINAS. Santafé de Bogotá, D. C.

Guerrero, J. (2002). A Proposal on the Classification of Systems Tracts: Application to the Allostratigraphy and Sequence Stratigraphy of the Cretaceous Colombian Basin. Part 1: Berriasian to Hauterivian. Geología Colombiana 27. pp. 3-25.

Guerrero, J. (2002). A Proposal on the Classification of Systems Tracts: Application to the Allostratigraphy and Sequence Stratigraphy of the Cretaceous Colombian Basin. Part 2: Barremian to Maastrichtian. Geología Colombiana 27. pp. 27-49.

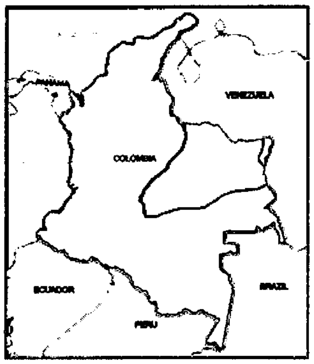
Mello, M., Trindade, L.A., Henz, G.I. & Francolin, J. (1995). The habitat of petroleum of the Tunja-Soápaga area, Upper Magdalena Basin, Colombia: A geochemical characterization of oil seeps and potential source rocks.

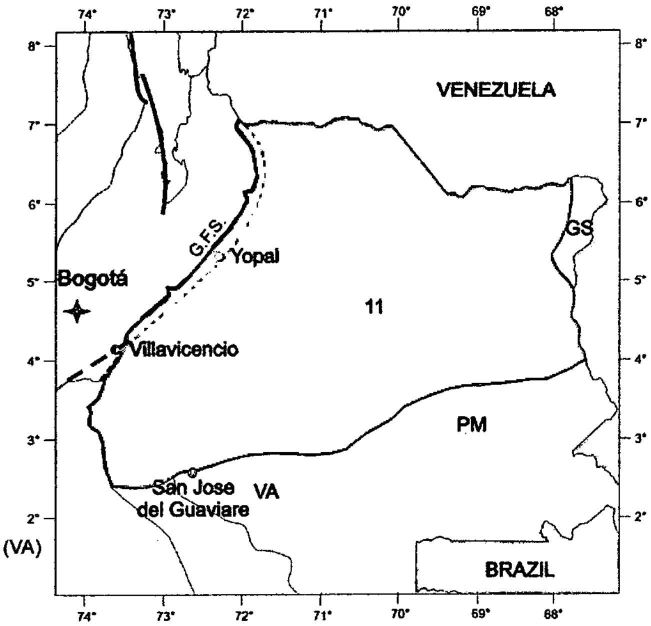
Ulloa, C., Rodríguez, E. and Rodríguez, G. (2003). Geología de la Plancha 172 Paz del Río. Memoria Explicativa. INGEOMINAS. Bogotá.

5. EASTERN LLANOS BASIN

The Eastern Llanos Basin is the most prolific hydrocarbon basin in continental Colombia. The northern limit of this basin is the Colombian-Venezuelan border; to the south the basin extends as far as the Macarena high, the Vaupés Arch, and the Precambrian metamorphic rocks that outcrop to the south of the Guaviare River. The eastern limit is marked by the outcrops of Precambrian plutonic rocks of the Guyana Shield, and to the west the basin´s limit is marked by the east-verging thrust system known as the Guaicáramo Fault System (Figure 1). The western portion of the basin is the well-known Llanos Foothills.

EASTERN LLANOS BASIN
LOCATION AND BOUNDARIES





BOUNDARIES

North: Geographic Border Venezuela

East: Guyana Shield Precambrian rocks (GS)

South: Serranía de la Macarena, Vaupés Arch (VA) and Precambrian metamorphics (PM)

West: Guaicaramo Fault System (G.F.S.)

SCHEMATIC CROSS SECTION
EASTERN LLANOS BASIN

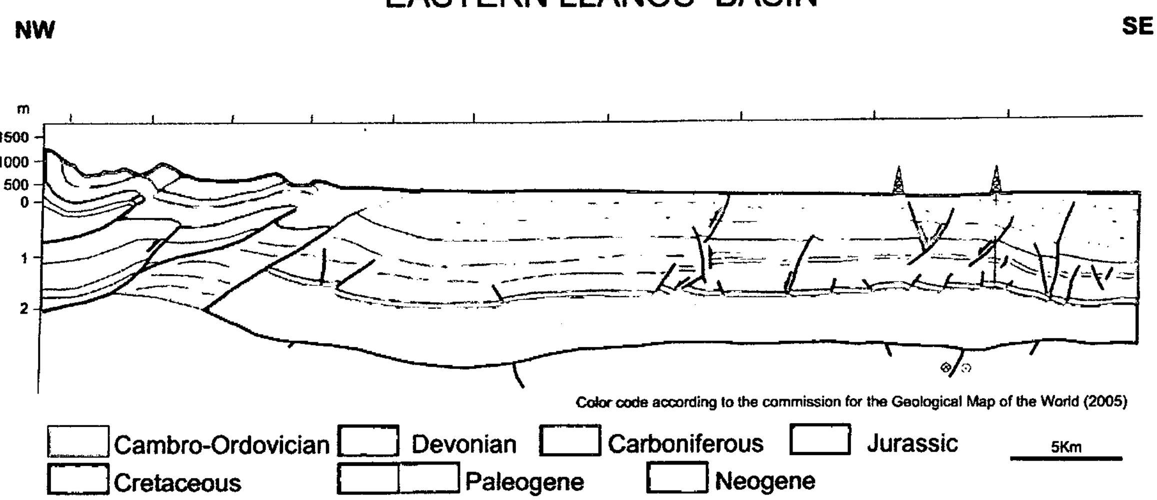


Figure 1. Eastern Llanos Basin.

AIRBORNE GRAVITY AND MAGNETIC SURVEY: EASTERN LLANOS BASIN, COLOMBIA. DATA PROCESSING REPORT[1]

Carson Helicopters, Inc. – Aerogravity Division

www.carsonhelicopters.com

2007

SUMMARY

Carson Aerogravity, a division of Carson Helicopters, Inc. conducted an airborne gravity and magnetic survey on Eastern Llanos Basin, Colombia, for the National Hydrocarbons Agency (Agencia Nacional de Hidrocarburos – ANH). Data from the airborne system are processed for acceleration, speed changes and departures from the flight reference surface made along each individual survey line. A profile is made for each survey line from the following parameters: topography, spring tension in milligals, Eötvös, GPS elevation, GPS PDOP, vertical accelerations calculated from the GPS data, average beam times "K" (i.e., "K" being a constant), and three plots of the free-air gravity with various levels of filtering. Once a line is accepted, a track plot map of the line is made. When the preliminary stage is completed, intersection analysis for all lines is performed on the parameters of gravity, magnetic and topographic surface.

OBJECTIVE

To perform the gravity and magnetic data acquisiton on Eastern Llanos Basin, Colombia.

[1] Airborne Gravity and Magnetic Survey. La Cuenca de los Llanos Orientales, Colombia. Data Processing Report. November, 2007.

GENERAL OUTLINES

Survey Area Description

In 2007 Carson Helicopters Inc. (Aerogravity Division) carried out the data acquisition of an airborne gravity and magnetic survey on the Eastern Llanos Basin for the National Hydrocarbons Agency (ANH). A DeHavilland twin outer turbo plane performed the acquisition of about 9270.5 km of gravity and about 9931.3 km of magnetic data respectively, on a 10 km x 20 km flight path. Figure 1 depicts the interpretation zone location. The Eastern Llanos Basin survey area is located between latitudes from 02°10'N to 05°20'N and longitude from 74°15'W to 70°00'W.

DATA ACQUISITION

Survey System

The airborne gravity and magnetic survey system, outlined below, was developed and patented by Franklin D. Carson and William R. Gumert in 1984 after years of extensive research and field testing. The Eastern Llanos Basin, Colombia survey was performed using a DeHavilland Twin Otter, N920R, fixed wing aircraft.

Navigation

Aircraft navigation is maintained through the use of the NAVSTAR Global Positioning System (GPS) and a real-time navigation system. Satellite signals are received by a single antenna contained in the RF unit mounted on top of the aircrafts where they receive the maximum signal strength with minimum interface. The antenna is right-hand circularly polarized, omni-directional in azimuth, and hemispherical in elevation.

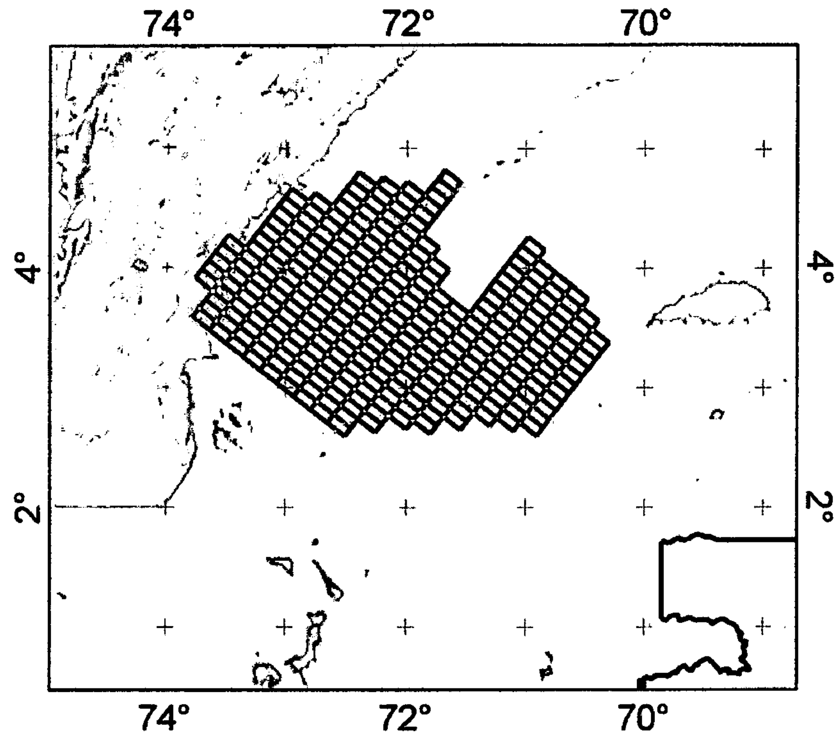


Figure 1. Survey Location Diagram.

Magnetometer

A Geometrics high sensitivity magnetometer was used. This device used a microprocessor unit in order to measure a continuous frequency signal received from one optically pumped Cesium magnetometer sensor mounted within a stinger under the aircraft tail section.

Automatic aeromagnetic digital compensator units are installed in the aircrafts to compensate or correct in real time the magnetic interference caused by the aircraft itself and aircraft maneuvering in the Earth's magnetic field, when using inboard mounted high sensitivity magnetometers. The compensations account for the effects of permanent magnetism, induced magnetism, Eddy currents also remove the heading errors caused by the sensors themselves. It provides a frequency bandwidth of DC to 0.9 Hz, the frequencies of greatest interest to the geophysicist. The signal(s) from the magnetometer(s) is (are) digitized faithfully without aliasing or phase distortion.

The variations of the Earth's magnetic field are recorded during flight in units of one tenth of a nanotesla at ten times per second sample rate on magnetic medium. The magnetic data is also recorded in flight on an analog paper strip chart for direct field monitoring. A magnetic base station, which records diurnal effect, will be set up and operated near the aircraft parking area at the airport used for the survey operations base. The magnetometer and recorder will be set up in a magnetically quiet area near this base and will be in operation during data collection times. These data will be used as a base constant comparison to the acquired flight data.

Altimetry

The Rosemount Model 1201F Pressure Transducer is designed to provide a highly accurate, high level DC output voltage linear with sensed absolute pressure. The excellent linearity of the output allows direct reading or recording of a highly accurate signal without additional correction or amplification. The Model 1201F utilizes a patented low stress, "free-edge" diaphragm design and a patented capacitance measuring circuit to achieve static accuracies of ±0.1% span.

The Honeywell HG7195A radar altimeter is pulsed radar, leading edge return system that measures the closest target to the aircraft. Closed loop leading edge tracking results in exceptional accuracy and prevents the tendency to track the centroid of the total return.

Random phased non-coherent RF transmission is used to eliminate Doppler effects. Distance measurements are based solely on transit time. Multipath energy and interference are removed by fully-gated leading edge tracking. Both a 0-25 volt D.C. stable and linear analog output and a serial digital output are provided to the data acquisition system.

Gravity Meter

The gravity meter used on all Carson Aerogravity surveys is the LaCoste and Romberg Air/Sea Gravity Meter (Model S). This meter is a highly overdamped, spring-type gravity sensor. It is mounted on a gyro-stabilized platform and has associated electronics for the recording of gravity measurements. The collected data values are recorded on both paper and magnetic medium.

The LaCoste and Romberg stabilized platform air-sea gravity meter consists of a highly damped, zero-length spring type gravity sensor mounted on a stabilized platform with associated control electronics and a recording system. Inertial navigation quality gyros are used for two-axis stabilization of the platform. The control electronics are completely solid state.

Data Processing Constants

Job Name:	La Cuenca De Los Llanos Orientales, Colombia	
Data Flown:	July 15, 2007 through August 31, 2007	
(Flight 1 through Flight 38 inclusive)		
Gravity Meter:		
LaCoste & Romberg Air/Sea Gravity Meter S-89		
Gravity Meter Constant:	0.9979	Milligals per counter unit
Base Gravity:	977.85253	Gals
Base Spring Tension:	9342.1	Counter units
Magnetometer:		
Base Magnetics:	31000	Nanoteslas

Data Evaluation

Data evaluation is multi-fold and begins with a video review of the field files. This review and the flight logs are examined to reveal any loss of data, out-of-tolerance information, or operational problems that may have occurred during a flight. The data are collected and recorded unfiltered in the field at a one-second-sample rate. The processing and evaluation of the data are performed on every record at a one second-sample rate.

A profile is made for each survey line from the following parameters: topography, spring tension in milligals, Eötvös, GPS elevation, GPS PDOP, vertical accelerations calculated from the GPS data, average beam times "K" (i.e., "K" being a constant), and three plots of the free-air gravity with various levels of filtering. A comparison of these plotted files with one another reveals the acceptability of a particular survey line's data.

Once a line is accepted, a track plot map of the line is made. This map, showing the location of the line in the survey area, confirms the line positioning and agreement or disagreement with contract specifications. When the preliminary stage is completed, intersection analysis for all lines is performed on the parameters of gravity, magnetic and topographic surface.

RESULTS

Computed Lengths Of Data Profiles

The La Cuenca De Los Llanos Orientales, Colombia survey consists of 44 survey lines. There are 18 gravity and magnetic lines flown at azimuth headings of either 38 or 218 degrees from north. There are 26 gravity and magnetic lines flown at azimuth headings of either 128 or 308 degrees from north.

	Gravity Data	**Magnetic Data**
Total Delivered Distance	9270,5 kilometers	9931,3 kilometers

The data are collected in 153 data profiles. There are 80 gravity profiles and 73 total magnetic intensity data profiles.

Data Profile Identification Description

Each data profile is identified by a seven-digit number (Figure 2). This number represents four distinct pieces of information:

1) Flight Direction (Figures 1 and 2)

2) Flight Number

3) Line Number

4) Reflight Number (necessitated by reflight of the line if the initial data are rejected).

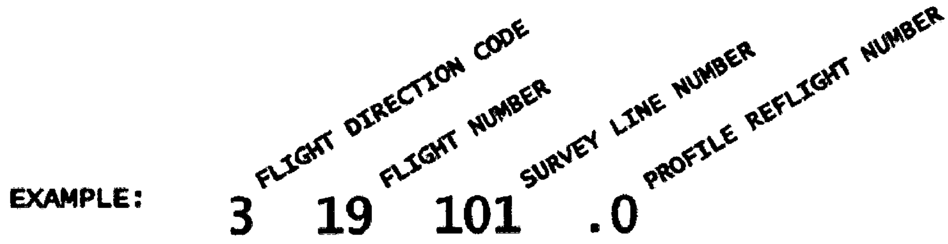


FIGURE 1
FLIGHT DIRECTION CODES

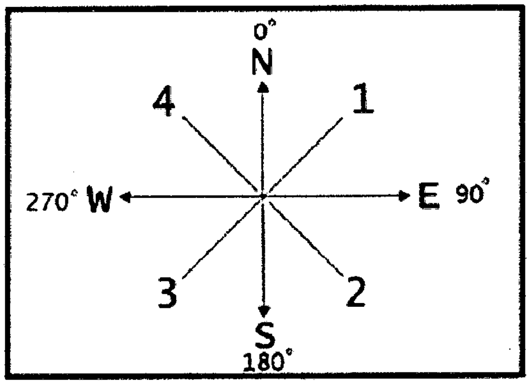


FIGURE 2
FLIGHT AZIMUTH VARIANCES

DIRECTION CODE	FLIGHT AZIMUTH
1	1° - 90°
2	91° - 180°
3	181° - 270°
4	271° - 360°

Figure 2. Data Profile Identification Description.

Gravity Data Profiles and Total Magnetic Intensity Data Profiles

Below examples of Gravity Data Profiles are shown:

PROFILE NUMBER 231201.1	NUMBER OF POINTS = 719
TOTAL LENGTH OF PROFILE	40.2 KILOMETERS.
LENGTH OF ACCEPTED GRAVITY	40.2 KILOMETERS.
TOTAL FLIGHT DISTANCE	9270.5 KILOMETERS.
TOTAL GRAVITY DISTANCE	9270.5 KILOMETERS.
TOTAL MAGNETIC DISTANCE	0.0 KILOMETERS.
TOTAL NUMBER OF PROFILES =	80

Below examples of Total Magnetic Intensity Data Profiles are shown:

PROFILE NUMBER 201204.0	NUMBER OF POINTS = 4196
TOTAL LENGTH OF PROFILE	207.1 KILOMETERS.
LENGTH OF ACCEPTED MAGNETICS	207.1 KILOMETERS.

TOTAL FLIGHT DISTANCE 9931.3 KILOMETERS.
TOTAL GRAVITY DISTANCE 0.0 KILOMETERS.
TOTAL MAGNETIC DISTANCE 9931.3 KILOMETERS.

TOTAL NUMBER OF PROFILES = 73

Figures 3-7 show Free-air Gravity, Bouguer Gravity, Total Magnetic Intensity and Terrain Elevation.

Gravity and Magnetic Data Color Plates

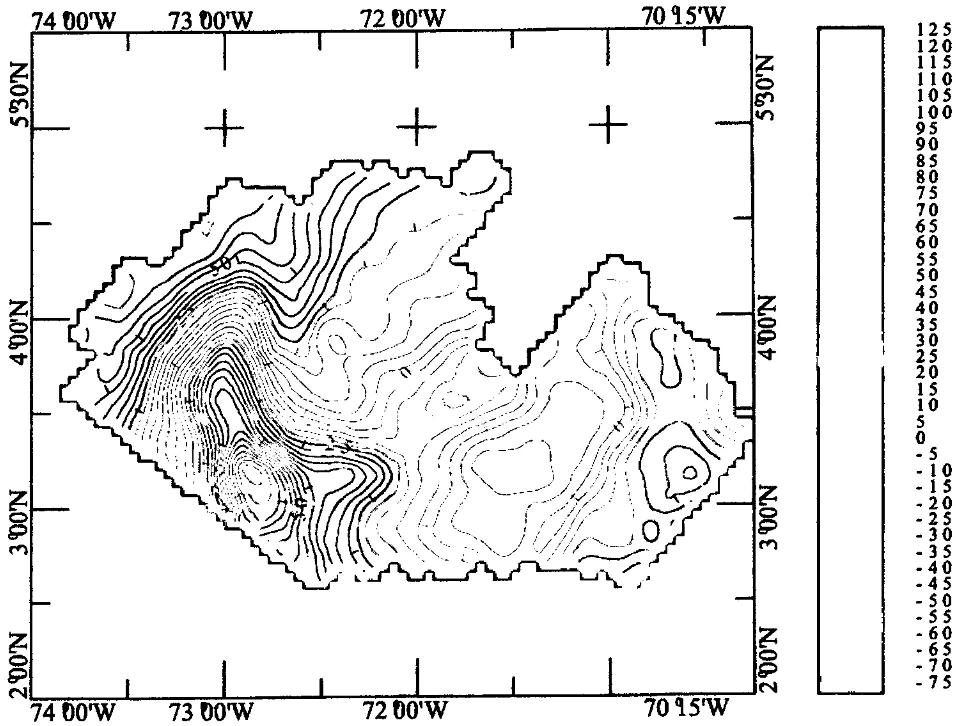


Figure 3. Free-air Gravity Final Adjusted.

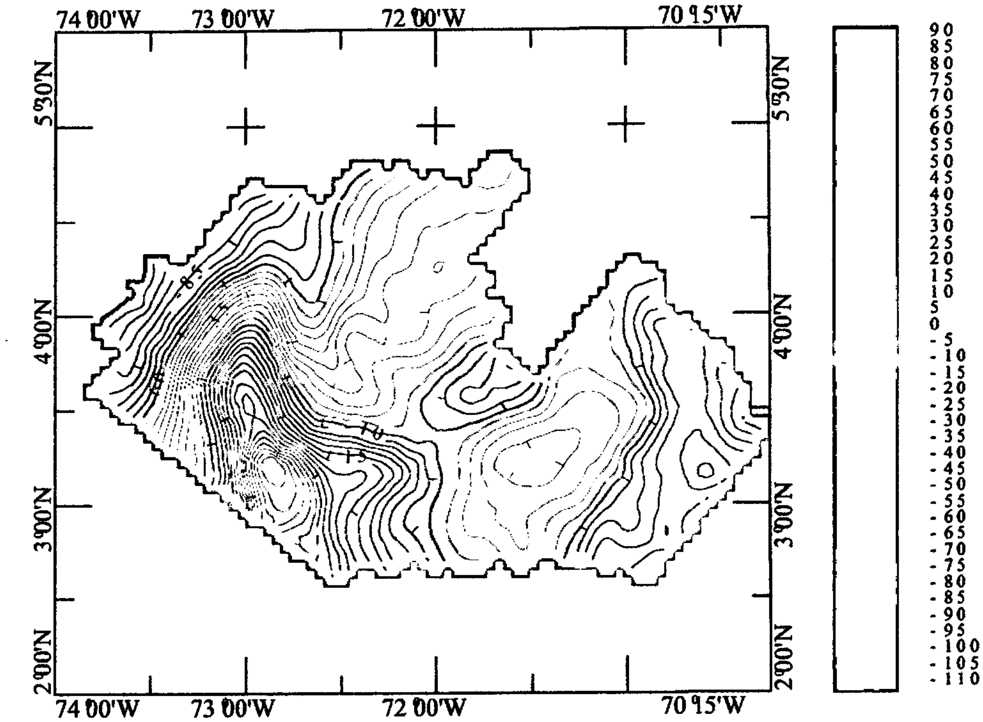


Figure 4. Bouguer Gravity 2.3 g/cm3.Final Adjustment.

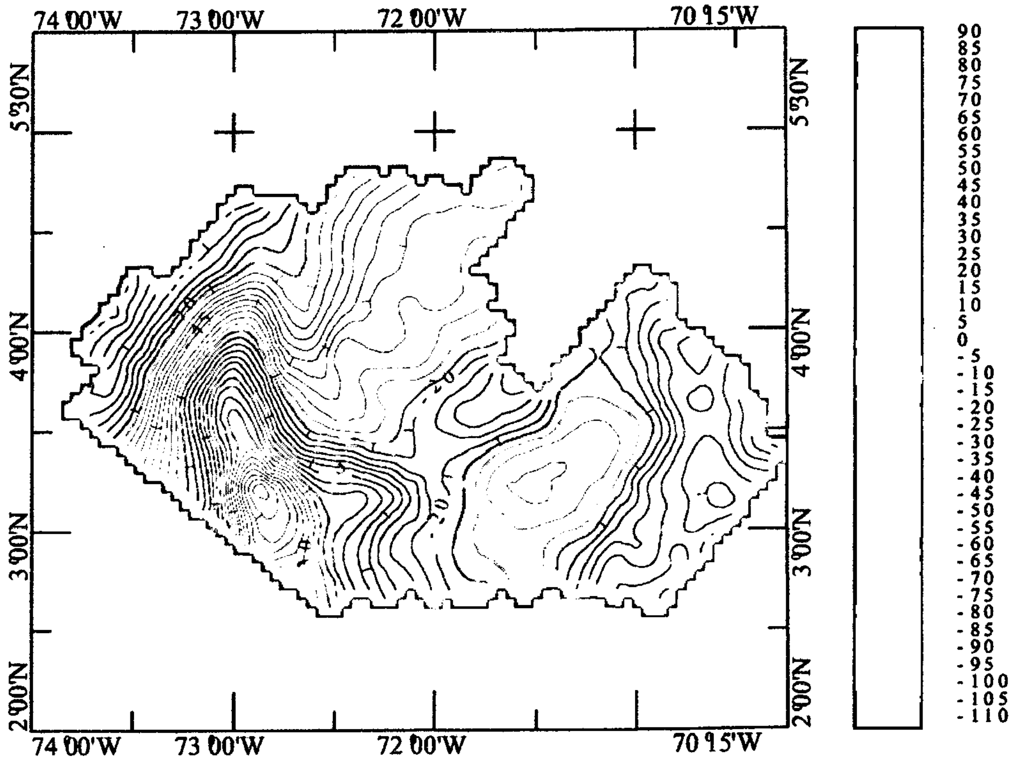


Figure 5. Bouguer Gravity 2.67 g/cm3.Final Adjustment.

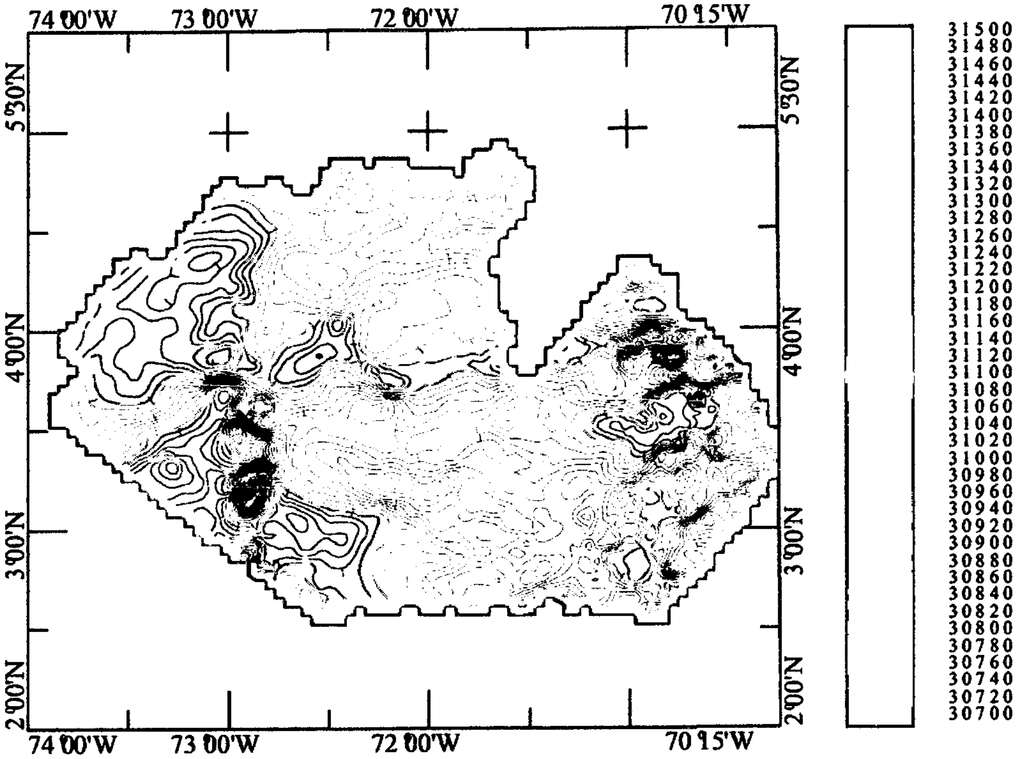


Figure 6. Total Magnetic Intensity (IGRF Removed) Final Adjusted.

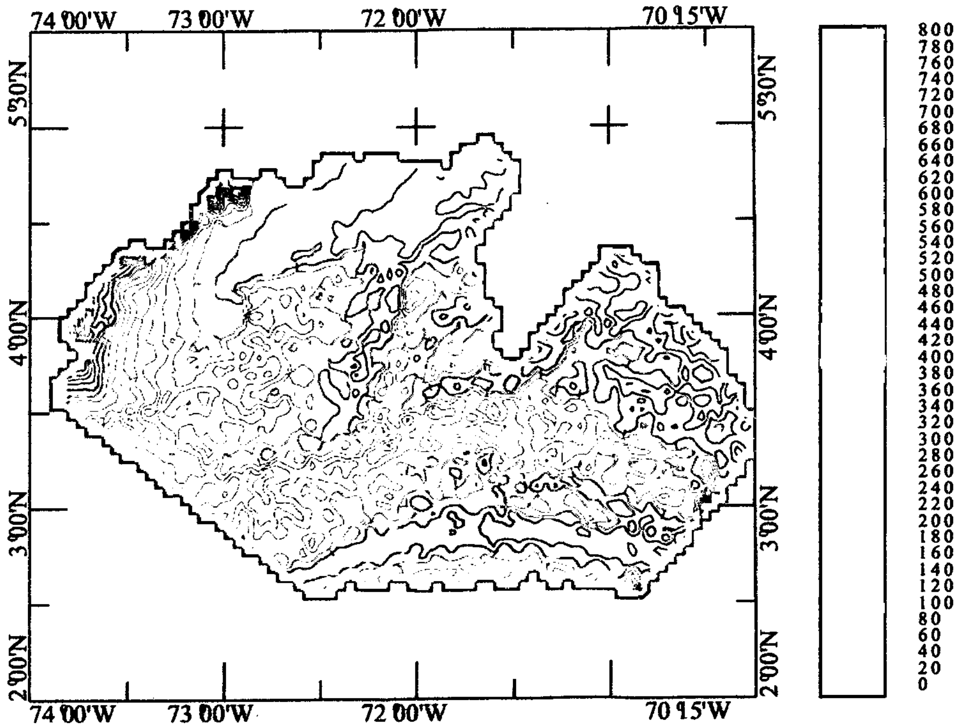


Figure 7. Terrain Elevation.

RESULTS

CONCLUSIONS

REFERENCES CITED IN THE ORIGINAL WORK

SEISMIC PROJECT EAST ARIPORO 85 - 2D[1]

PetroSeis Ltda.

www.petroseis.com.co

2006

INTRODUCTION

This Project includes a re-processing of 448 kilometers of seismic survey, corresponding to 18 lines of the East Ariporo 85-2D project, located at the Eastern Llanos Basin, acquired by EXXON Enterprise during years 1985 and 1986 (Figure 1). A total of 3149 records were processed.

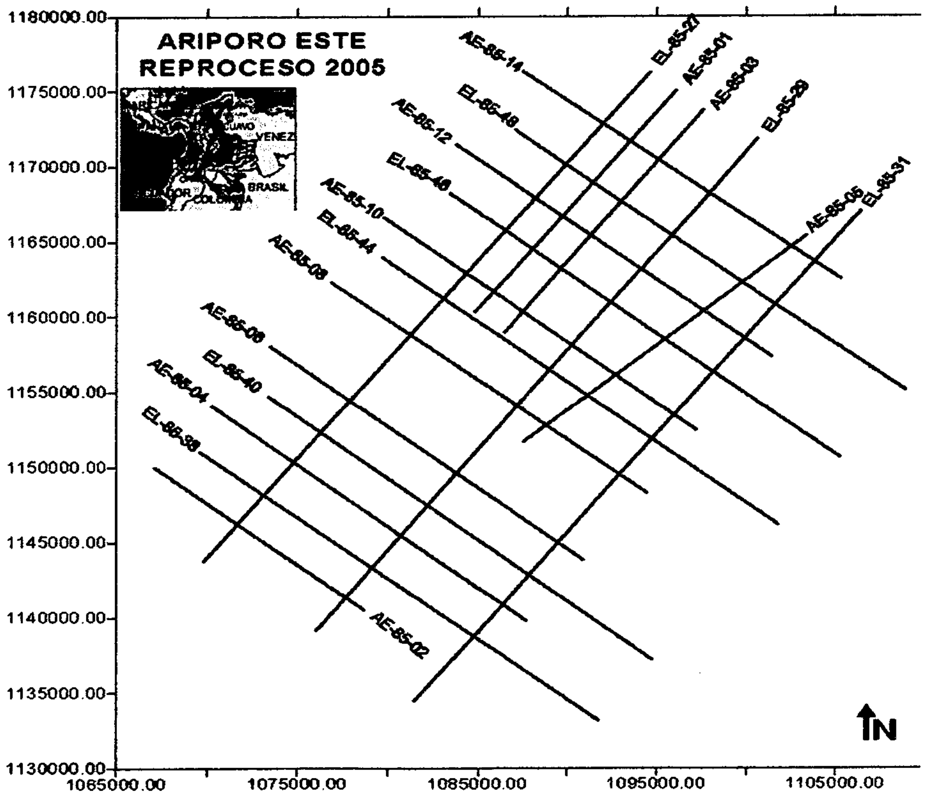


Figure 1. Location and geometry of the project.

---

[1] Informe final de procesamiento. Ariporo Este 85-2D. PetroSeis Ltda. Enero 2006.

OBJECTIVE

The obtainment of a good seismic image of the area, with the purpose of improving its geological model.

Table 1 shows the field work parameters:

Table 1. Parameters of acquisition of the program.

TYPE OF INSTRUMENT	DFS-V
RECORDING FORMAT	SEG B
SAMPLING INTERVAL	2 ms
RECORD LENGTH	3 s
NUMBER OF DATA CHANNELS	96
COVERING IN SUBSOIL	60%-120%
POWER SOURCE	DYNAMITE
DEPTH OF SOURCE	60 ft
AMOUNT OF LOAD	1 lb
NUMBER OF WELLS	1
LOW CUT	12 Hz. 18 dB/oct
HIGH CUT	128 Hz 72 dB/oct
NOTCH	OUT
TYPE OF GEOPHONES	GS - 20D / 10 Hz
ARRANGEMENT OF GEOPHONES	12 IN PARALLEL EVERY 4.16 m
DISTANCE BETWEEN RECEIVERS	25 m
DISTANCE BETWEEN SHOTPOINTS	100 m – 200 m

METHODOLOGY

The methodology carried out during the realization of the seismic processing is summarized in the following steps:

- Entering of information from SEGY tapes handed in by ANH.
- Assigning and review of the geometry and picking of first arrivals.
- Elaborating of first amplitude recovery tests, consistent amplitude analysis on surface, deconvolution and spectral balance, in order to define the initial parameters of the pre-stack process sequence. The parameters were chosen taking as reference the quality of the record and stacking.
- Having defined the pre-stack sequence, the solving of the static problem was undertaking; for this, static solutions were obtained by elevation and refraction. Velocities were picked every 0.625 km afterwards for each solution and the stacking was carried out.

- As the next step, the velocities were reviewed, and the second static residuals were applied.
- Additionally, a NMO correction was made by applying "stretch mute" and post-stacking mute.
- Migration was carried out using the Finite Differences algorithm.
- Lastly, the final presentation was carried out, and this report was elaborated.

General parameters

For the processing of this project, the following parameters were used:

Reference plane: 150 m.

Replacement Velocity: 1800 m/s.

Sampling interval: 2 ms.

Maximum processing time: 3 s, Block AE – 1985; 4 s, Block EI - 1985.

Process description

Input data

The information issued to the processing center, was made up of EXABYTE tapes in SEG-Y format, which later on, were converted into internal ProMAX format.

Geometry

The geometry is composed of independent electronic sheets for receivers, sources, and patterns of spreading. In order to fill out these spreadsheets, the information from the observer reports of each one of the issued lines was used. Afterwards, the assignment of this information was done by automatically loading the information from the database to the headers of the traces. Quality control was carried out in order to corroborate whether the position of the shots was the correct one by deploying all the records with a correction by Linear Moveout.

In the same way, quality control was carried out for the receivers. Besides this, quality control was carried out for the graphics in the database, considering the offset, elevation on the surface for shots, as well as for the stakes, covering, number of channels and first live channel by source, and distribution of CDP velocity and offset.

True amplitude recovery

This program offers several options for true amplitude recovery (such as, spherical divergence and inelastic attenuation), which can be used separately or combined. This algorithm applies to the trace a variable gain function in time for compensating loss of amplitude due to attenuation and dispersion inherent to the propagation of power through subsoil. Using tests that were carried out for various options, the most adequate parameter for applying was determined, in this case it was 1/[dist] in a time window of 3000 ms.

Surface consistent amplitude recovery

The value of amplitude depends on various factors. These factors include the energy of the source, the response of the receivers, the channel amplification response, the distance between traces, the contrast of density and velocity of the reflectors and other factors that can contain the environmental noises.

It is difficult to separate the contribution of each one of these factors in one single trace. The contribution can be statistically estimated in many traces. The Surface Consistent Ampls. tool estimates and adjusts the relative amplitudes in source, receiver, offset, CDP and channel, over a surface consistent base. For calculation, the Shot, Receiver, Offset, CDP and Channel components on each of the lines, were used.

Trace-by-trace deconvolution

The registered seismic information is considered as the convolution of the signal from the source with the subsoil, the instruments, and the geophones. The ground response includes unwanted effects, for which attempts of removal were made, applying inverse filters through deconvolution. These effects are considered as linear filters. Keeping in mind the objective of the project, it was decided favorable the use of deconvolution of the spiking type. Tests were conducted with operator lengths of 80, 160 and 240 ms and a white noise percentage of 0.1%.

Spectral balance

At this stage, the traces are transformed to the frecuency domain, where the spectrum is enhanced based on calculated gains, according to some intervals defined by the processor, with the purpose of improving data quality. The parameters defined by the processor were the following:

- Type of filter: invariable with time.
- Frequencies for spectral swing 5 - 15 - 115 - 120.

Refraction statics applications

The static corrections are constant adjustments of time applied to each seismic trace with the purpose of correcting anomalous travel times produced by topography variations, or changes in velocity and thickens of the shallow layers (low velocity layers or meteorized layers). The basic objective of these corrections is: to determine the reflections arrival times, as if all the measures had been taken on the same plane, without the presence of meteorized layers, low velocity zones, or height differences.

Figure 2 shows a refraction velocity obtained by using Promax software, which uses Delay-Time algorithm with 150 m datum and a processing speed of 1800 m/s.

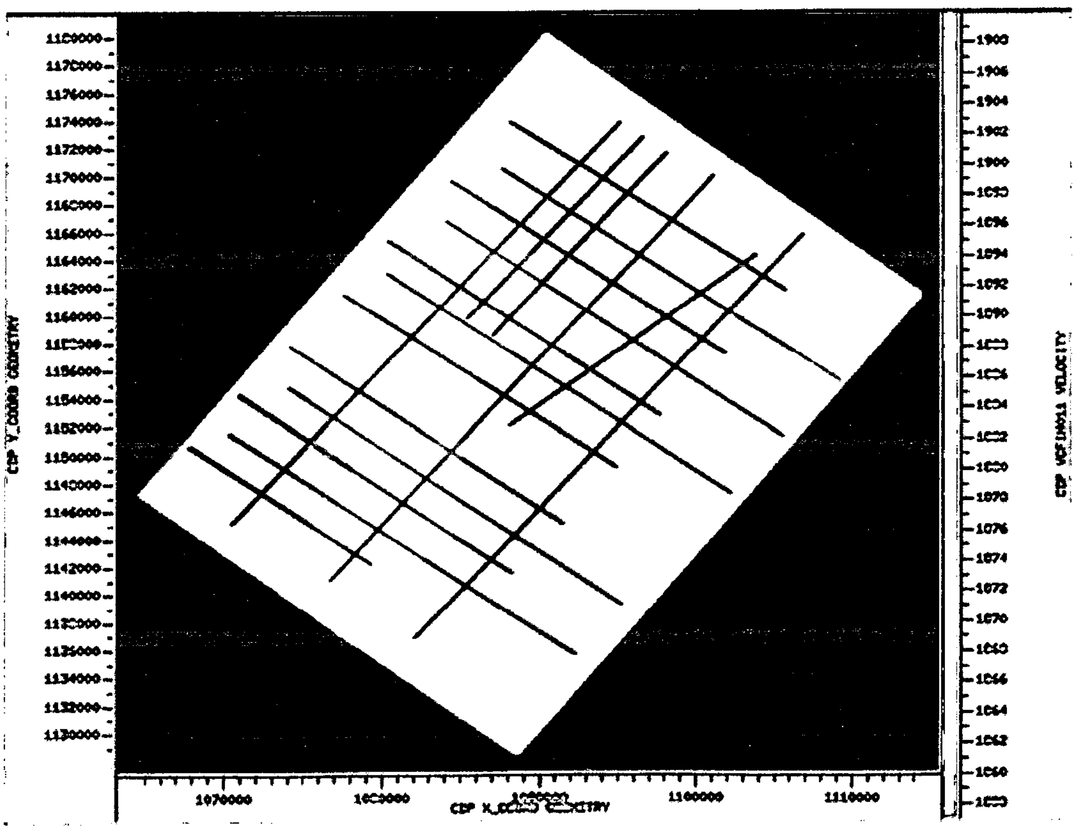


Figure 2. Map of refraction speed (velocity) calculated for the project.

NMO and muting Correction

The Normal Moveout Correction tool was applied for velocities obtained in the second analysis, with a Stretch Mute of 30%.

Surface-consistent residual statics

In order to calculate the residual statics, the method called "Maximum Power Autostatics" was applied. It consists in selecting source and receiver statics, which maximizes the stacking response. "Maximum Power Autostatic" is effective for a broad range of information qualities.

The parameters chosen were the following:

Algorithm: Maximum Power

Type: Flat Window

Number of Iterations: 4

Maximum allowed static: +/- 16 ms.

Stacking by CDP

CDP's were grouped and added for generating stacking.

Migration

Post-stack time migration was carried out. In order to perform this migration, a Fourier transform was applied passing from the time domain to the frequency domain, and from the distance domain to the wave number domain, which is quite precise in areas that have weak lateral variation of speeds velocities.

In order to obtain migration velocity, final stacking velocities were taken to a flat Datum plain and smoothed with a one kilometer operator. From this field, a velocity function was extracted, and it was migrated with velocity percentages, in order to define the field for the final migration by Finite Differences.

The parameters chosen were the following:

Algorithm: Finite Differences

Speeds (velocities): Smoothed stacking

Percentage: 100%

Post-stacking processing

FX deconvolution was applied in order to elevate the signal/noise ratio. The resulting trace should have less aleatory noise than the entering trace.

The parameters used were:

Bandpass filters

Frequencies 8 - 12 - 90 - 100 Hz.

FX-deconvolution

White noise percentage: 10% horizontal window length: 15

Variable scaling in time

Gain values: 1.5 – 1.0 – 1.0 – 1.5 – 0.7

Some examples of obtained results are shown as following:

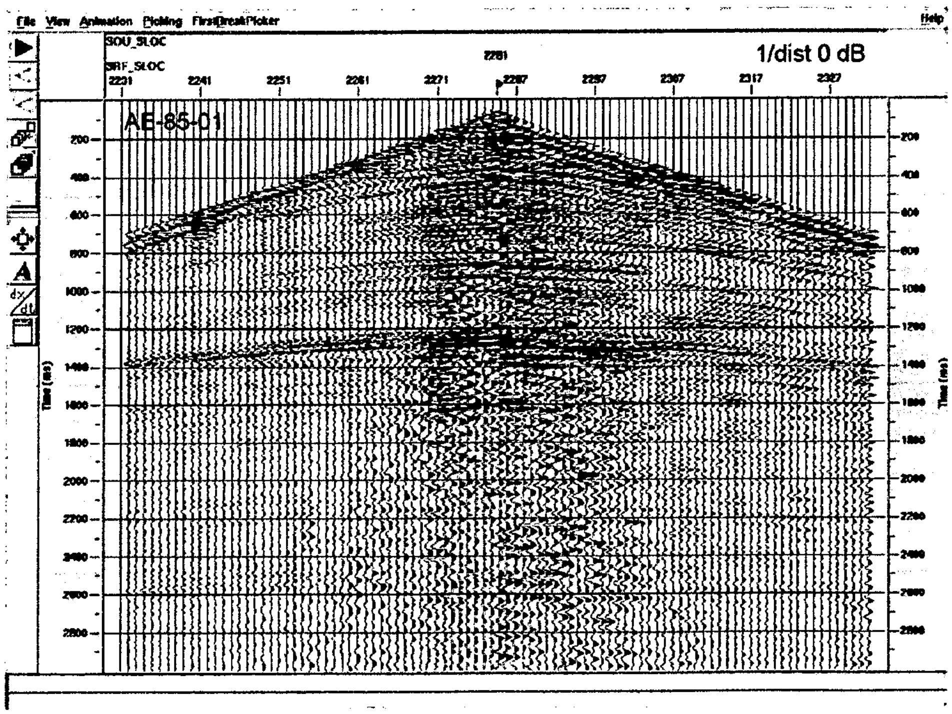


Figure 3. Example TAR test.

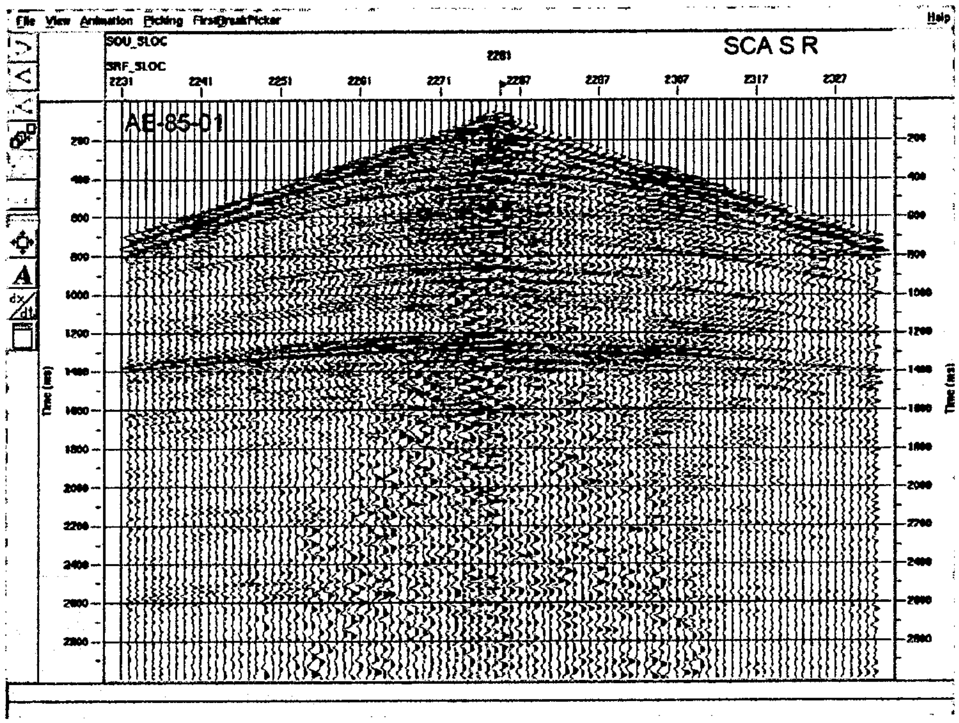


Figure 4. Example SCA test.

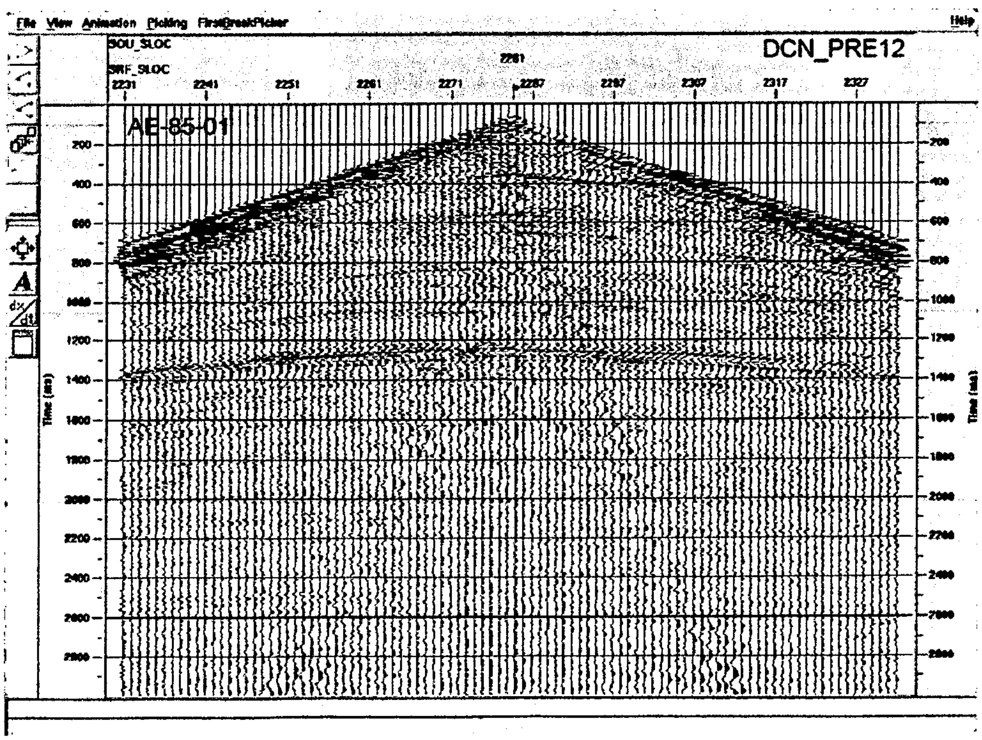


Figure 5. Example DECON test.

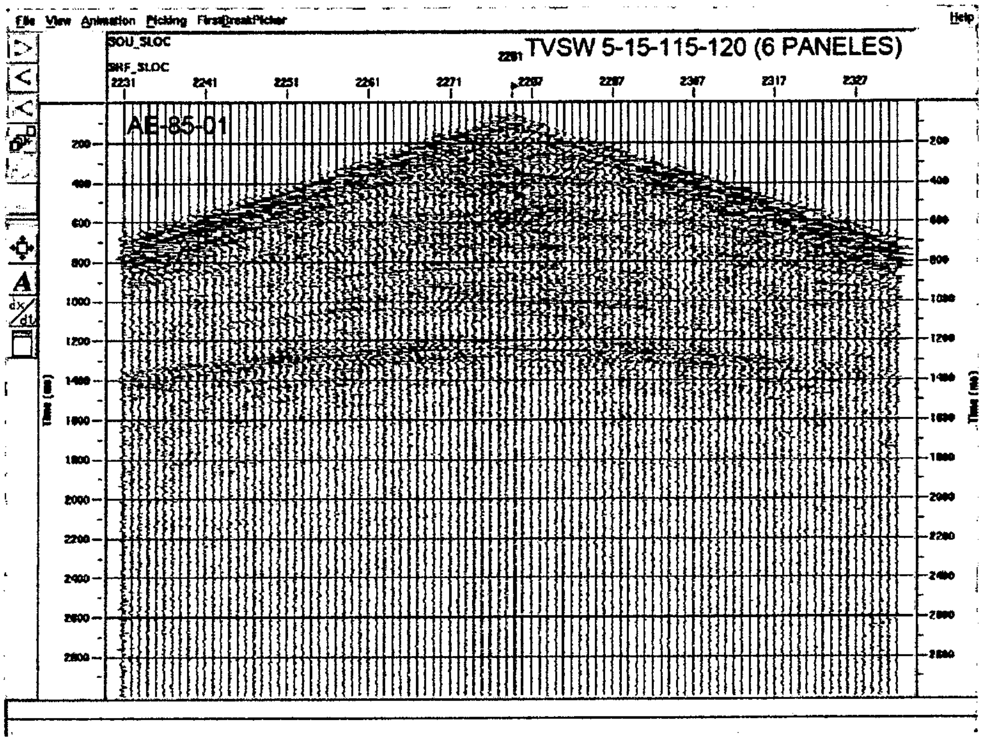


Figure 6. Example TVSW test.

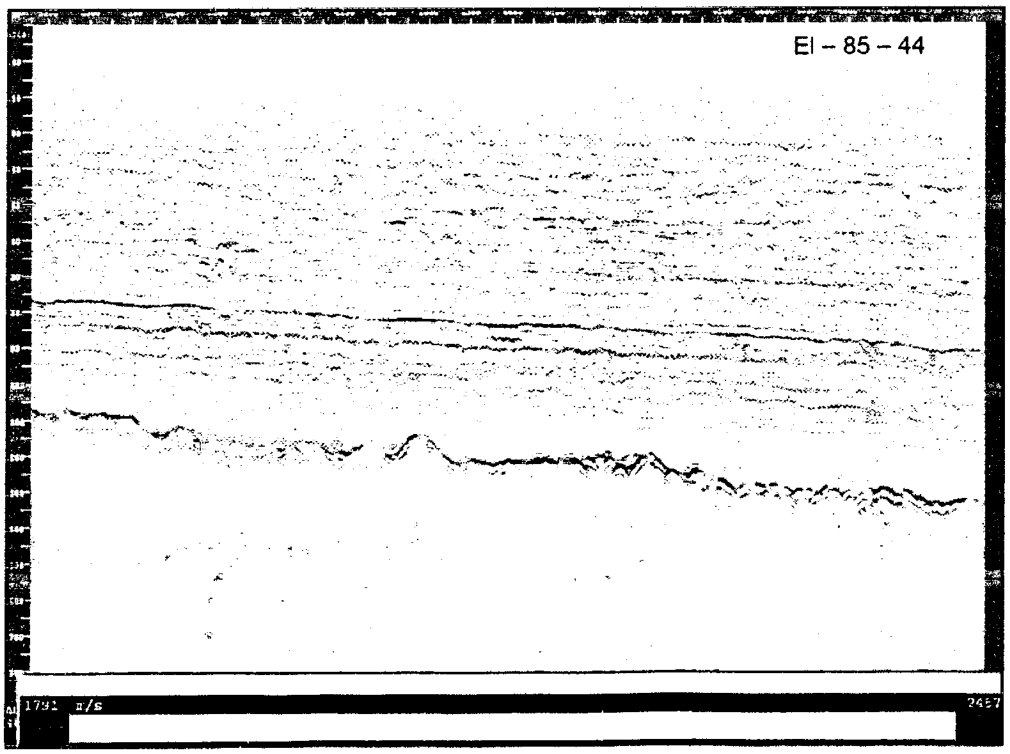


Figure 7. Example of velocity field.

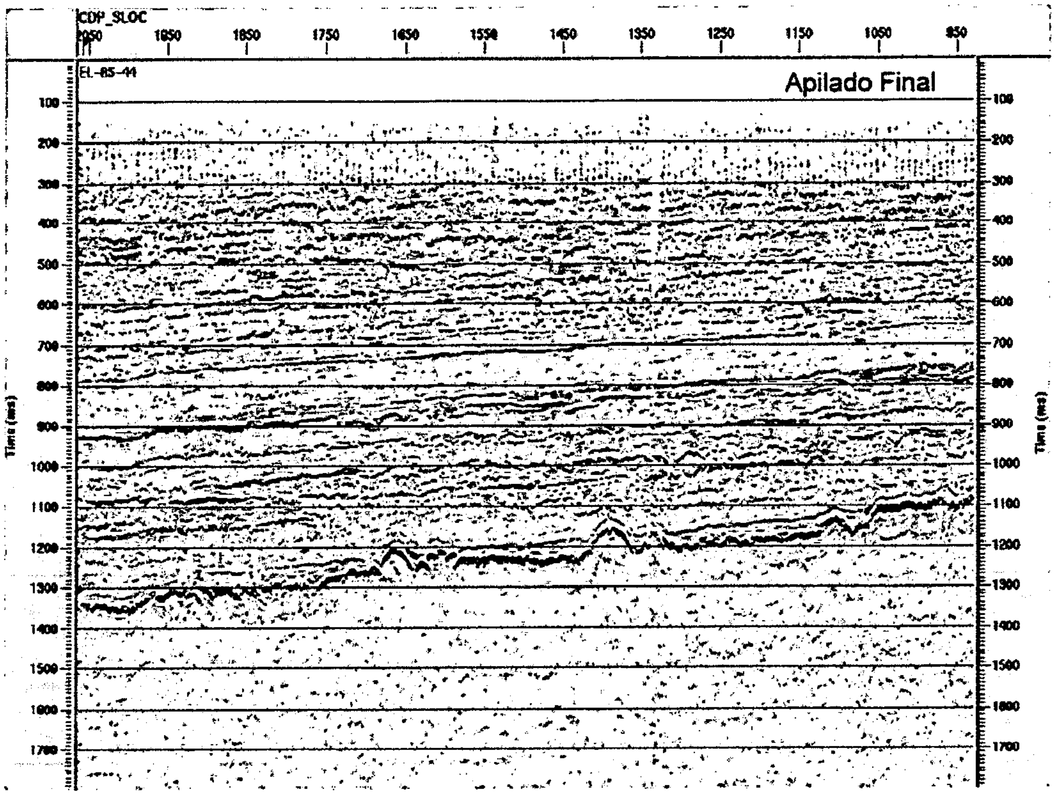


Figure 8. Example of final stacking.

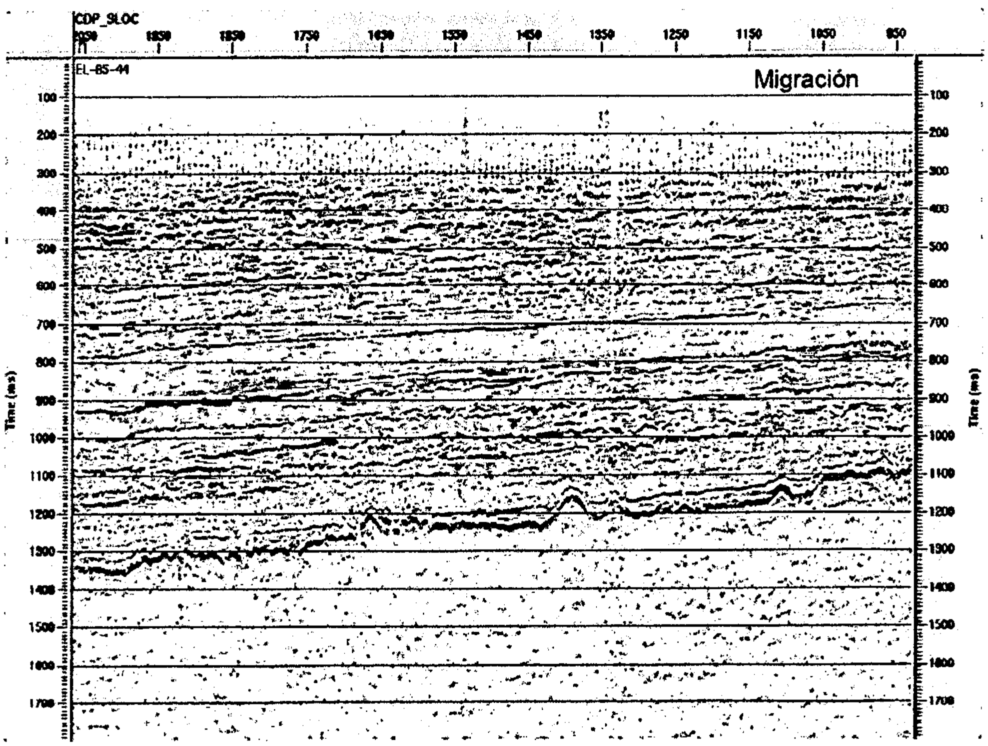


Figure 9. Example of migration.

FINAL PRODUCTS

- 1 Exabyte 8mm copy of final stacking and migrations OUT-OUT (all lines).
- 1 Exabyte 8mm copy of final stacking and migrations IN-IN (all lines).
- 1 copy of final velocity stacking (all lines).
- 1 copy of the Processing Final Report and final stacking and migrations displays.
- 1 film copy of the final stacking and migration (all lines).
- 1 copy in TIFF format of the final stacking and migration (all lines).

CONCLUSIONS

The velocity analysis allowed to obtain a velocity field with few lateral variations and an increment of its time value, which facilitated to get the final velocities migration field.

The good quality is related to the conservation of the predominant frequency range and the picking of detailed velocities.

REFERENCES CITED IN THE ORIGINAL WORK

SEISMIC PROJECT LLANOS 2D FINAL REPORT OF PROCESSING AND INTERPRETATION[1]

UNION TEMPORAL KPITAL GEOFISICA

www.sngf.ru

2006

SUMMARY

the processing, interpretation and geological modeling of seismic data are obtained in this report as a result of the Seismic Reflection 2D Survey in the Eastern Llanos Basin. The plan was to process and interprete 741.2 km of regional seismic profiles, but finally four profiles were carried out for a general extension of just 296.6475 km.

OBJECTIVE

To identify the principal seismic reflectors in the northeast sector of Eastern Llanos Basin.

LOCATION

The area of research is located in the eastern part of the Republic of Colombia, in the zone of the Eastern Llanos Gaseous-Petroliferous Basin. From the administrative point of view, the area is located in the eastern part of the Meta Department and in the western part of the Vichada Department, between the Meta and Guaviare rivers (Figure 1).

---

[1] Proyecto sísmico Llanos 2D. Informe final de procesamiento e interpretación. Tomo 1. Guanapé-Vichada. Diciembre 2006.

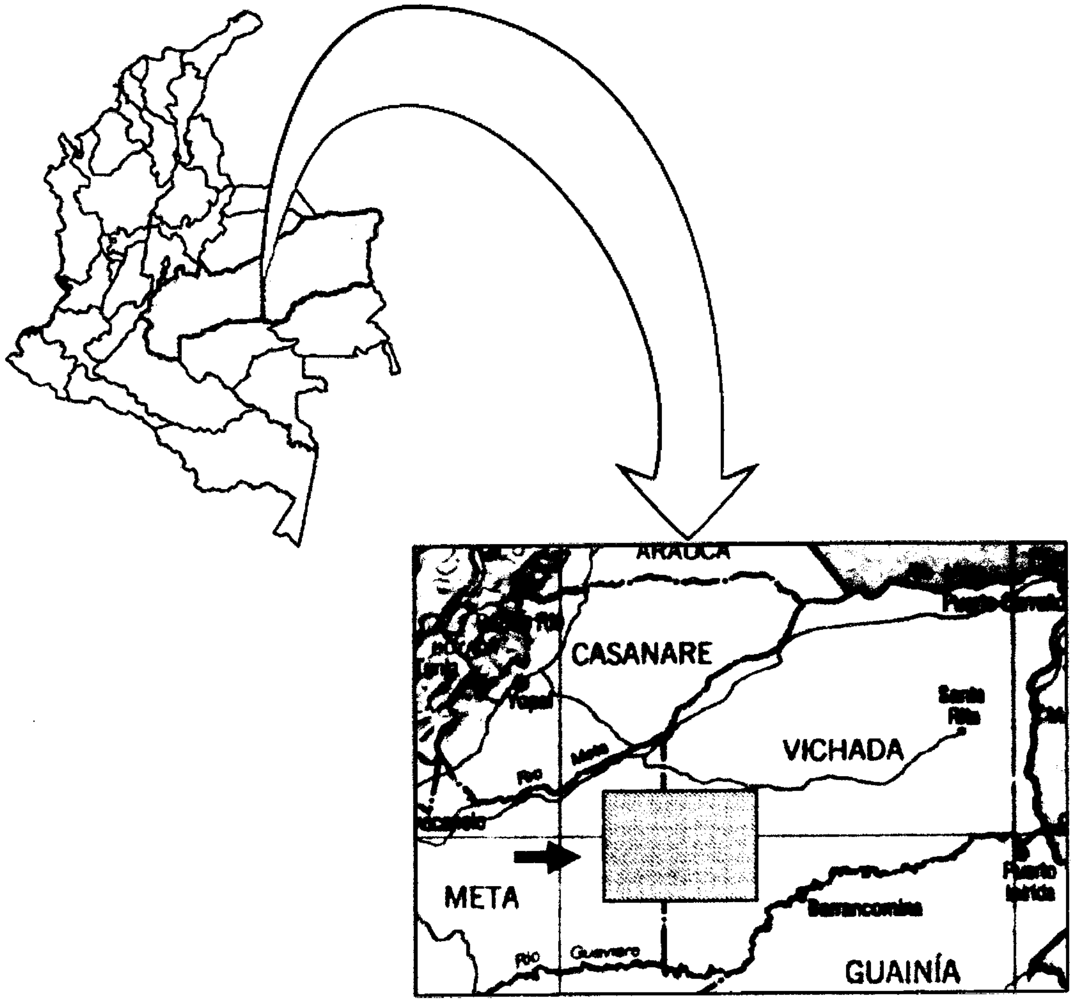


Figure 1. General map of location of the area.

The geophysical works (seismic reflection 2D survey) in the Eastern Llanos Basin, have been carried out since 1957. Until now, about 96000 km of the reflection 2D seismic profiles have been carried out. Most of these profiles were realized in the western part (foothill) of the basin. The eastern edge of the platform is covered by sporadic network of regional profiles and those of recognition, elaborated by various companies in different years (Figure 2).

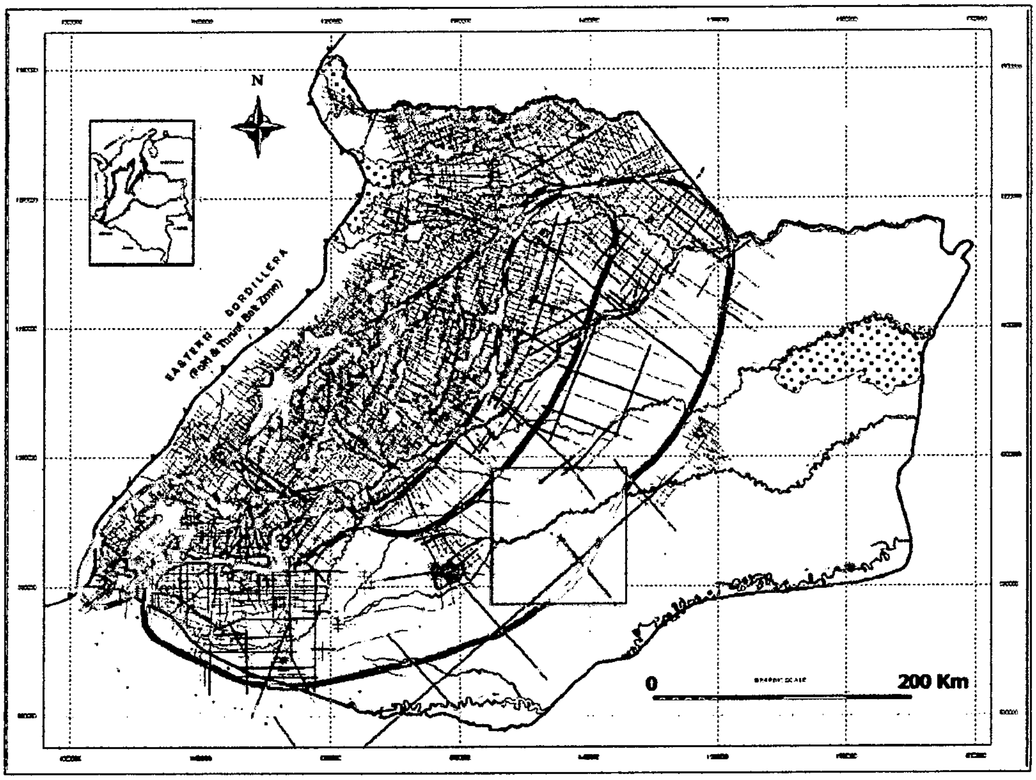


Figure 2. Outline of seismic studies carried out at the Eastern Llanos Basin, based on information issued by ANH.

METHODOLOGY

Characteristics of the field records quality

During the data quality control process, some technical defects were found. They occurred at the moment of carrying out the registration. These problems are: High noise level and exaggerated elevation of channel amplitude near the shot point, in comparison to the most distant channels in seismograms at the common shot point. At the stage of field records selection, no more than 3% of the general channels were excluded. The total data subjected to basic processing covers 296.6475 km.

Software

Field seismic data processing was carried out with the help of the Geo_luster Plus Program (CGG, France). Its interpretation was carried out with the GeoGraphix Discovery Program (Landmark, USA). As a result of the research, the prospective geological horizons were revealed.

Field Work Parameters

In Table 1 the field work parameters are shown:

Table 1. Field work parameters.

Type of instrument	I/O SYSTEM FOUR
Sampling interval	2 ms
Record length	5 s
Cutting filters	
BF (LF) Low frequency):	out
AF (HF) (high frequency):	187.5 Hz.
Band-pass filter:	out
Recording format:	(32 bit) SEG - Y IEEE
Recorded in:	DVD-ROM
Shot parameters:	
Energy source:	Dynamite
Charge pattern;	1 x 25
Charge:	900 g
Distance between receivers:	30 M
Registration parameters:	
Geophone:	VECTOR SIX
Frequency:	12 Hz
Number of channels:	240
Grouping pattern:	On line
Location of the geophone:	Central
Covering:	60
Distance between the group centers:	12 m

Selecting of processing parameters sequence

Due to the fact that properties of each sedimentary layer are specific, if in different located tests the used conditions are the same for the shot point and for the receiver, in general, the results will be different. In order to get an optimal result, that would be ideal for a specific geological purpose, processing parameters were taken independently for each study area. The sequence of seismic processing can be seen in Figure 3.

Proofs of fundamental parameters of the processing sequence were used in a fragment of the ANH-LL-2005-6280 profile between shot points 1001-4001. Parameters were selected for the following processes: amplitudes recovery, deconvolution, band-pass filters, elimination of average velocity noise waves, coherent filtration in seismograms of shot points, elimination of aleatory noise (random noise), migration, etc.

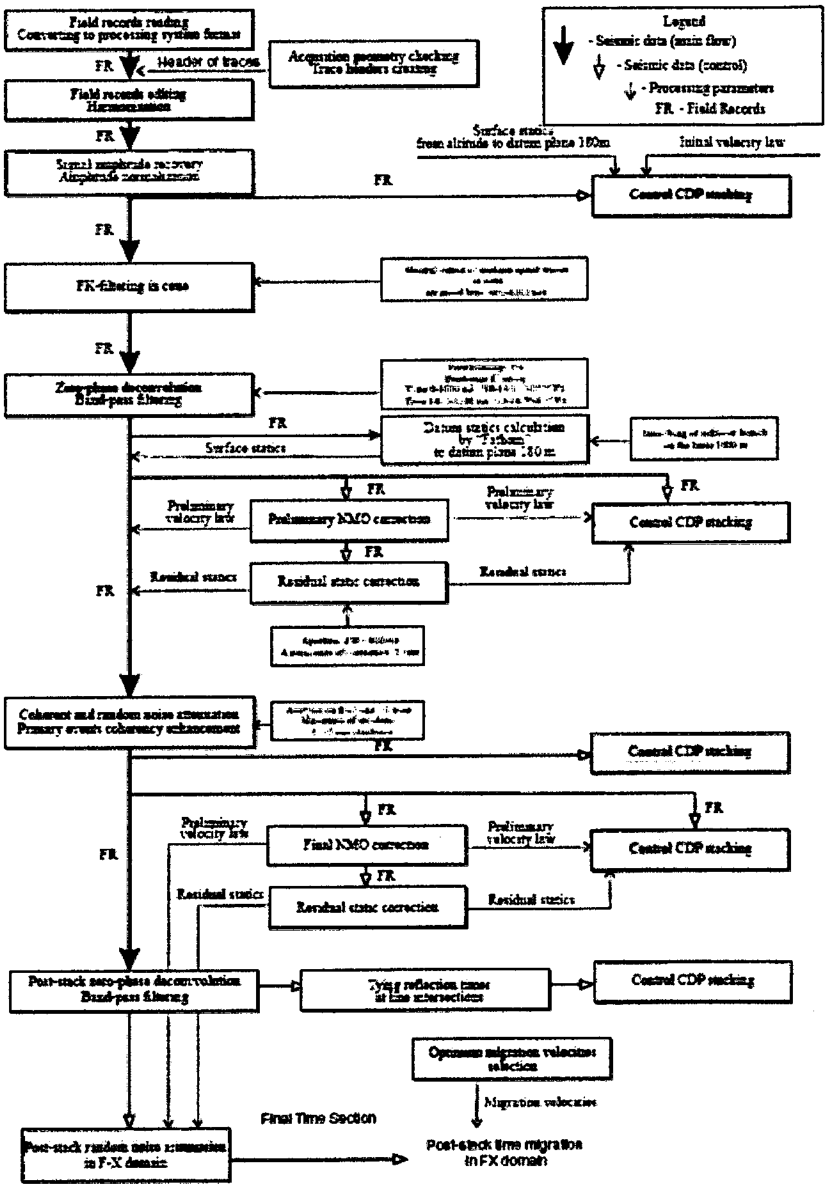


Figure 3. Basic processing Sequence

RESULTS

Interpretation of seismic records was done with aid of Discovery GeoGraphix interpretation program (Landmark US) A total of 296.6475 km of seismic profiles were interpreted. The velocity parameters and conversion methodology at depth are shown in Table 2:

Table 2.

Horizon	Function	Velocity (m/s)
L1	H=1220(T) – 154	1874 – 2127
C1	H=1250(T) – 174	1880 – 2150
C3	H=1310(T) – 215	1938 – 2215
C5	H=1320(T) – 222	2005 – 2250
C7	H=1630(T) – 619	2005 – 2250
pCarb	H=1410(T) – 280	1998 – 2390
pPZ	H=1500(T) – 320	2140 – 2733

In the waves fields of the processed seismic sections in the Eastern Llanos Basin, from downward to upward, seven seismographic complexes can be clearly seen, differentiated one from the other by the seismic record characteristics. Only the second one and the third one, corresponding to strata of Carbon Eocene Formation and Upper Paleozoic, are of interest from the hydrocarbon search point of view. The change from one reflection to another, is illustrated in Figure 4.

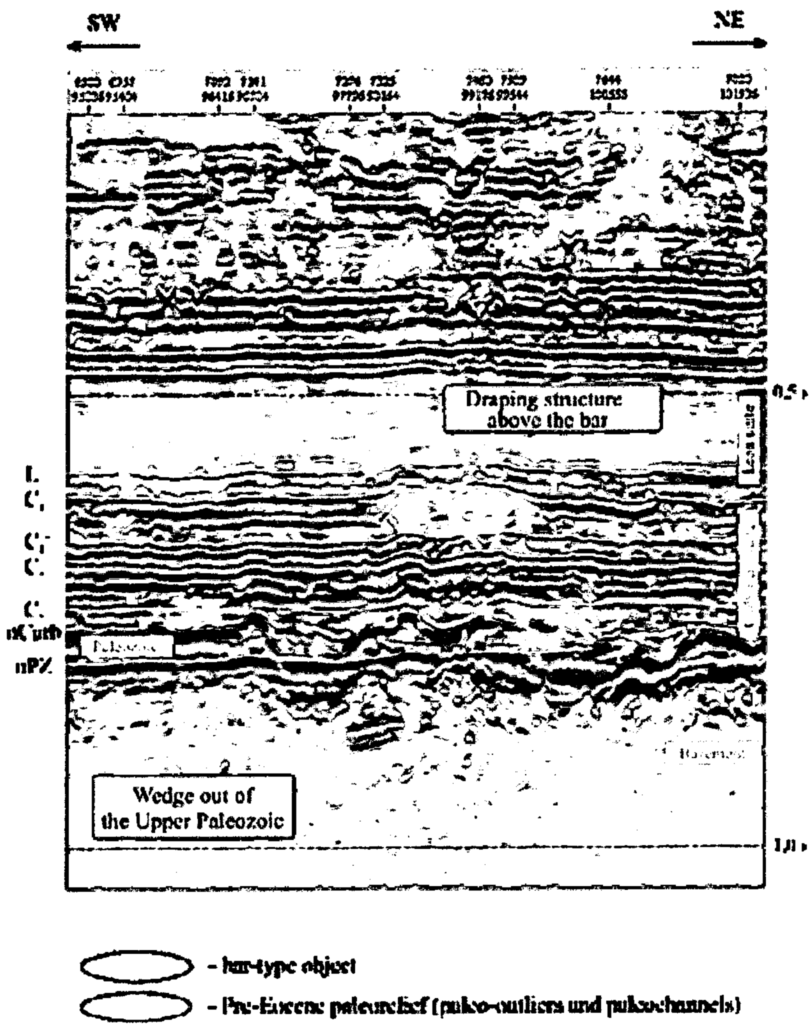


Figure 4. Fragment (A) of the cross section - profile ANH-LL-2005-0920.

CONCLUSIONS

- In the Upper Paleozoic sequence, Carbonera and León Formation, structural and stratigraphic traps were identified. They are of interest from the oil and gas search point of view.
- The better part of stratigraphic and other type of traps were identified in the Carbonera Formation.
- The stratigraphic traps are associated to anticlinal folds, and they have structural origin, as well as stratigraphic one.
- Stratigraphic traps are associated to paleo-reliefs of the Late Paleozoic, and to crystalline Basement, which represent paleo-intrusive evidences, zones of basal deposit and zones of horizon wedging, which are located at the upper part of the sequence. The stratigraphic traps are associated to surface of sediment of the Upper Paleozoic and Superior Eocene (Carbonera Formation)

REFERENCES CITED IN THE ORIGINAL WORK

HEAVY CRUDE OIL AREA - PROSPECTING REPORT[1]

HALLIBURTON

www.halliburton.com

2008

SUMMARY

The Heavy Crude Oil Project is divided into 4 stages:

On the first stage the work team focused its task in the gathering of information from the study area (Figure 1) from approximately 12 Colombian governmental companies in charge of managing technical information associated with hydrocarbon prospecting and production in Colombia. Later on, at this stage, a project backup was prepared, excluding any formation rated as confidential by ANH.

The second stage was focused on the selection of the most important information available in the ANH, and on its interpretation, in order to determine the potential of prospecting resources in the blocks designed by ANH.

On the third stage the "data room" scheduled by the ANH was prepared,

On the fourth stage Halliburton coordinated the data room in Bogotá and participated in Houston and London data room during 2008.

[1] Área Crudos Pesados. Informe de Prospectividad. 2008.

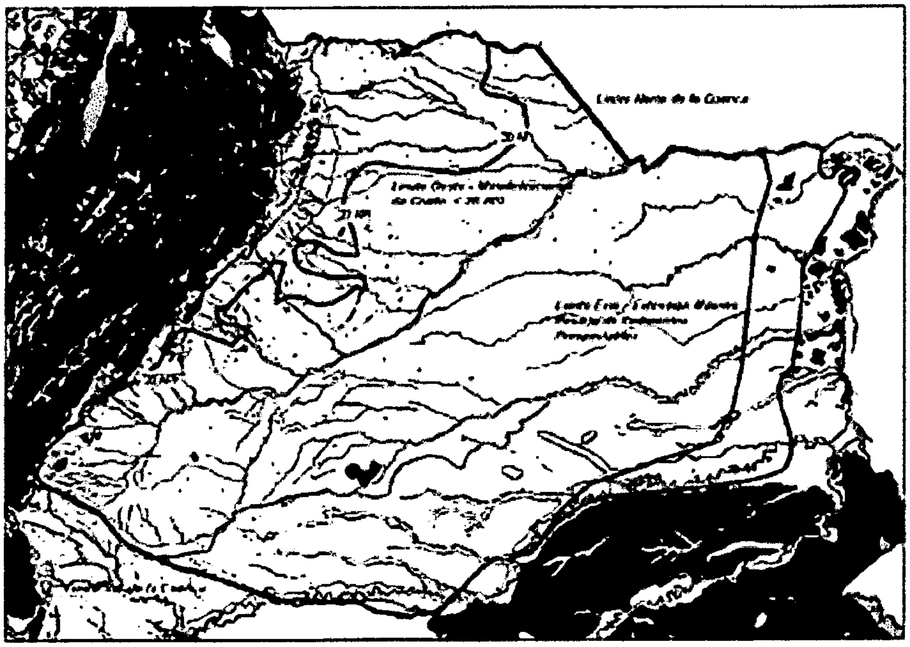


Figure 1. Location of study area (marked by red line).

Processed Information

To evaluate the prospecting potential of the "Special Area", Halliburton interpreted around 8300 km^2 of seismic lines surveyed during the project implemented in 2006 and another one developed between October 2008 and March 2008.

Oil and physical information from 36 wells located near the identified prospecting areas was also used, and information collected on civil and petroleum infrastructure was taken into account.

A result of this interpretation was the preparation of distribution maps of potentially producing areas, and structural maps for some of these units, which determined the maps of potentially prospecting areas.

Three regional stratigraphic sections were also prepared north, center and south of the special area.

Exploratory Potential

As a result of the work performed by the Halliburton-Landmark team, 40 prospecting areas were found, which yielded the following values:

Total area of exploratory opportunities

The forty interpreted prospecting areas were estimated as follows:

1750734 Acres	708497 hectares	P 10	Minimal Case
8695432 Acres	3518916 hectares	P 50	Medium Case
16877416 Acres	6830048 hectares	P 90	Maximal Case

Not-risked exploratory resources (STOIIP)

For 40 areas potentially productive of hydrocarbons, the following volumes were estimated:

390746	MMBBLS	P 10
914915	MMBBLS	P 50
1702392	MMBBLS	P 90

Geologic Risk

To estimate the geologic risks, the following equation was used:

POS = Probability (Structure) + Probability of (Reservoir) + Probability of (Seal) + Probability of (Load). Geologic risk was estimated to be around 15%, ranging between 7% - 27%, and it was calculated for each of the 40 leads.

Risked exploratory resources

Bearing in mind the estimate geologic risk, the following volumes were estimated:

54044	MMBBLS	P 10
122057	MMBBLS	P 50
222203	MMBBLS	P 90

EUR Potential (applying the Probabilistic Recovery Factor)

Although Halliburton believes that each company shall make its own calculations of both prospecting resource and risked resources and the potential of reserves, an estimate was also made of prospecting resources after applying a probabilistic recovery factor for each opportunity, ranging between 6%-47%, with a more probable 12% value.

Volumes below were estimated as follows:

8760	MMBBLS	P 10
22927	MMBBLS	P 50
57850	MMBBLS	P 90

INFORMATION CONTAINED IN THE PROJECT

Available Seismic Information

96000 km of 2D Seismic are available in the Eastern Llanos Basin, 15750 km of which are loaded for the project. All seismic information was provided by the ANH. In the Special Area are 434 lines amounting to 11501 km as shown in Figure 2. Selected seismic information is an integral part of 72 seismic programs recorded in the basin between 1973 and 2005.

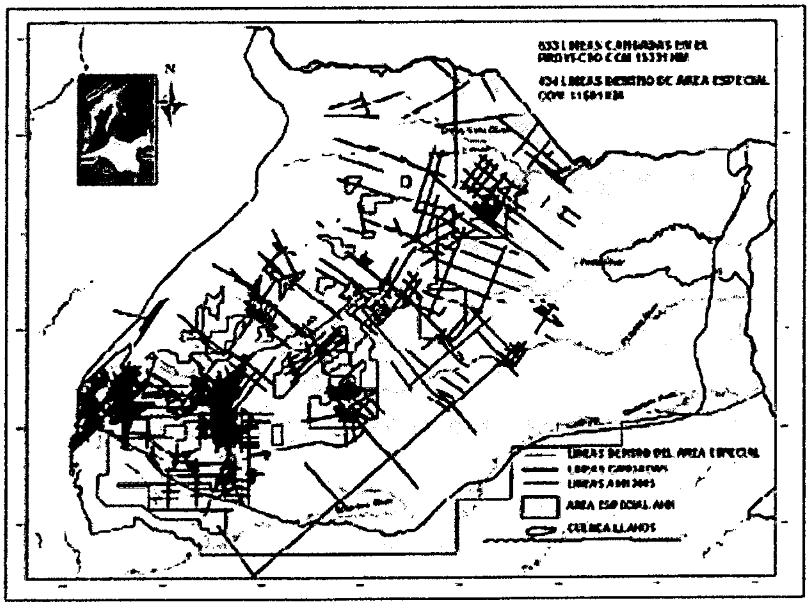


Figure 2. Seismic coverage map of the special area.

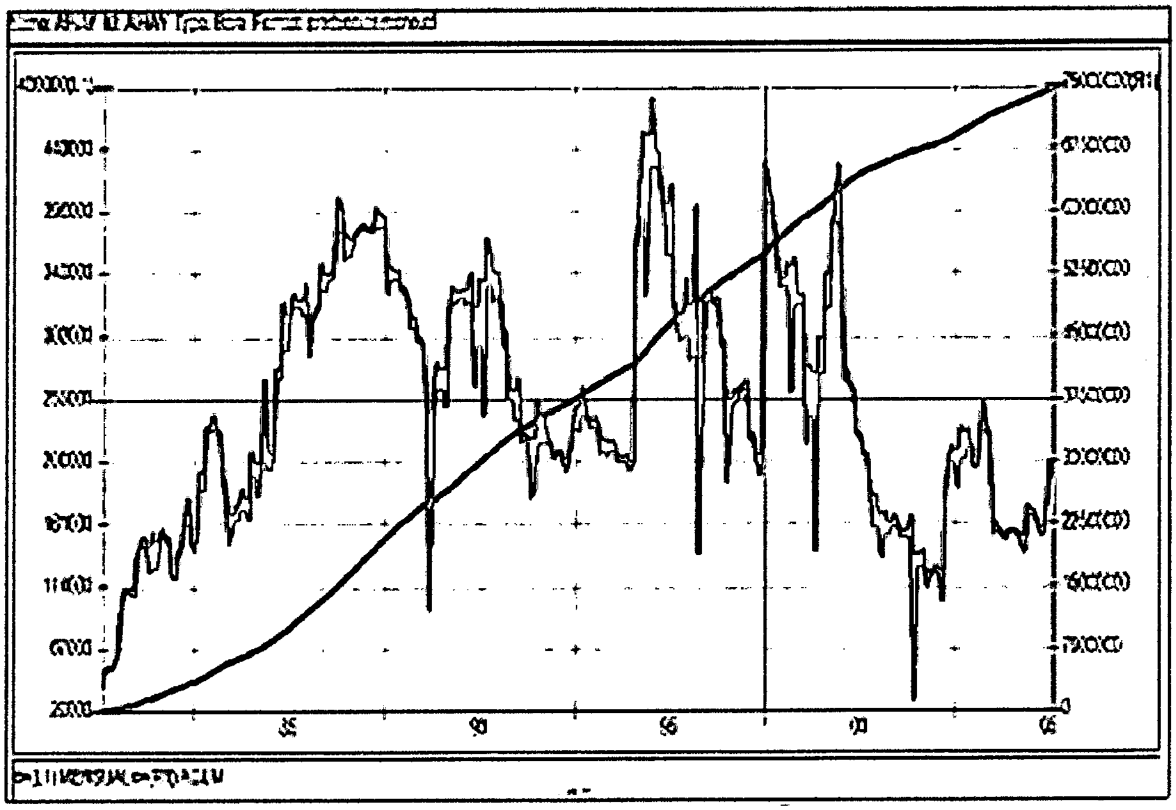
Aerogravimetric and aeromagnetometric information

Aerogravimetric and aeromagnetometric information provided by ANH is a part of a program acquired and interpreted during 2007. The gravimetric and magnetometric lines are 80 and 73, respectively, evenly distributed in the

Information contained in the database on production and oil engineering for Eastern Llanos Basin includes the Official Forms of the Ministerio de Minas y Energía MM&E (Ministry of Mines and Energy) for the different wells in the area, which are:

- Form 4 CR 16 wells
- Form 5 CR 18 wells
- Form 6 CR 35 wells
- Form 7 CR 8 wells
- Form 10 CR 29 wells

FORMS 9 provided by MM&E for 135 producing fields are included from an aggregate number of 145 reported ones. Below is an example of a production chart generated by with above information.



OIL BARRELS vs. DATE (YEAR)

Figure 4. Example of Chart of generated production.

List of reports

The database of heavy crude oils contains records of approximately 4929 technical reports and documents, which mainly includes: regional studies, evaluation studies of potential oil reservoirs, geochemical studies on rocks and oils, on oil systems, biostratigraphical and palynologic studies, structural evaluation, petrophysical and stratigraphycal studies, drilling records with tests data, completions and production, facilities for wells and fields, infrastructure information, topography, environmental evaluations, natural parks, reserves of natives, seismic, geophysics in general, and gravimetric and magnetometric information.

Geology and Geophysics

Area description

The Eastern Llanos Basin embraces a large area of Llanos territory. Most of the special ANH area is located in this basin, as shown in Figure 5, and involves an approximate area of 154000 km^2.

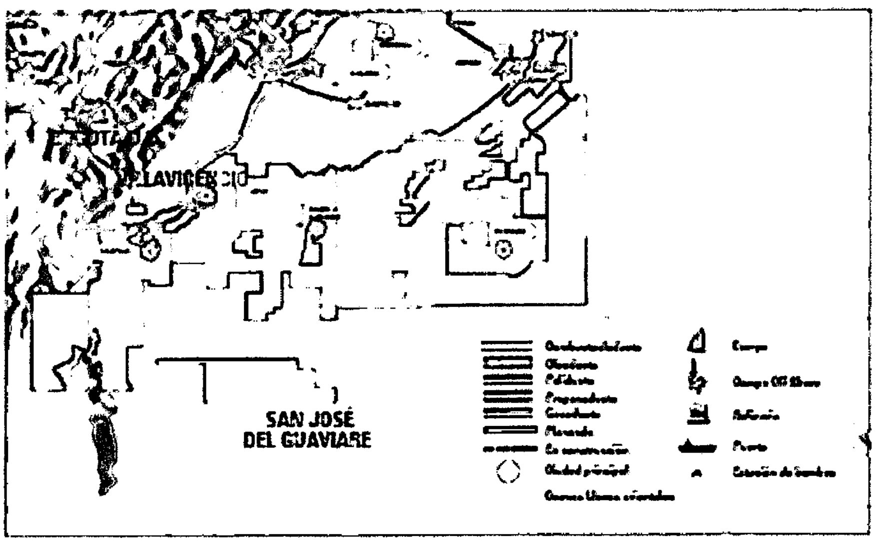


Figure 5. Location map of ANH Special Area.

Stratigraphical sequence

Sedimentary stratigraphical sequence of Eastern Llanos contains rocks with ages ranging between the lower and recent Paleozoic mainly silicoclastic, which lies on rocks of Guayana shield. It reaches its greatest thickness (15000-20000 feet) in the western border of the basin near the folded and deformed foothill of Eastern

Cordillera. Sediments so far proven to contain hydrocarbons of economic importance have been those of the Cretaceous and Tertiary ages. They form wedges separated by erosion surfaces, increase their sickness toward the east and are deposited on peneplanized surfaces of the Paleozoic or directly on methamorphic igneous basement. Identified units were: Une, Gachetá, Guadalupe, Mirador, Carbonera and León formations.

Surface geology

During the information collecting process, geologic maps were obtained at 1:1000000 and 1:500000 scales from INGEOMINAS, and geological maps of the Eastern Llanos Basin and Caño Sur Block of ECOPETROL at 1:250000 and 1:100000 scales.

Structural model

According to the tectonic frame of the Eastern Llanos Basin, its structural configuration is given by diverse tectonic episodes from the Paleozoic to recent periods. The Paleozoic limit is a disagreement representing a 200 million year hiatus and is a regular surface with a slope toward the northeast and sub-paralleled to the underlying stratification. In Alto Melón-Vorágine, Upia and Castilla-Apiay areas the Paleozoic shows a steep relief due to a greater structural deformation.

Over the discordance continued the sedimentary filling from the Cenomanian up to the middle Miocene with a hiatus in the heavy crude oil area of approximately 30 million years between the Guadalupe Formation and the Mirador Formation. Tectonic elements of greater importance, associated with the basin are the Llanero foothill fault systems, which originally being extendable structures, underwent reversal during the main deformation stage, which began as of the middle Miocene with the rising of the Eastern Cordillera.

Oil reservoir systems

Conventional and heavy crude accumulations in the Eastern Llanos Basin show the presence of active oil reservoir systems and support their elements and processes.

The Gachetá tertiary oil reservoir systems have contributed to a total production of more than 98% reserves of 2.8 BB BO crude oil.

The following are proven oil reservoirs systems in the area of the Eastern Llanos Basin:

- Gachetá-Une-Guadalupe oil reservoir system
- Gachetá-Mirador oil reservoir system
- Gachetá-Carbonera oil reservoir system

Main source rock

Gachetá formation

Shale contained in the documented Gachetá Formation of Upper Cretaceous, deemed the main source rock (Figure 6), was deposited under anoxic conditions over the sea transgression on a wide platform opened during the late Cretaceous. Lithology (mainly shale) in the axial zone and in the eastern portion of the generating prism is associated with an excellent Kerogen type II, rich in hydrogen. The content of organic carbon (TOC) usually ranges between 1.5-3.0% WT, with an average 2.2% WT. Organic matter contained in the generating rock is mainly non-structured of amorphous type with small particles of vitrinite. Hydrogen rate of immature samples has a maximum 200 mg HC/g TOC, which is increased by the rase of the thermal maturity to values approximately equal to 400 mg HC/g TOC, a condition indicating that these rocks generate oil.

Secondary source rock

Shale rich in organic matter and good thermal maturity grade contained in Los Cuervos, Mirador and Carbonera (C8) tertiary formations, locally and toward sectors of eastern Eastern Cordillera Foothill typical in areas of Cusiana-Cupiagua fields, are deemed secondary source rocks (Figure 6).

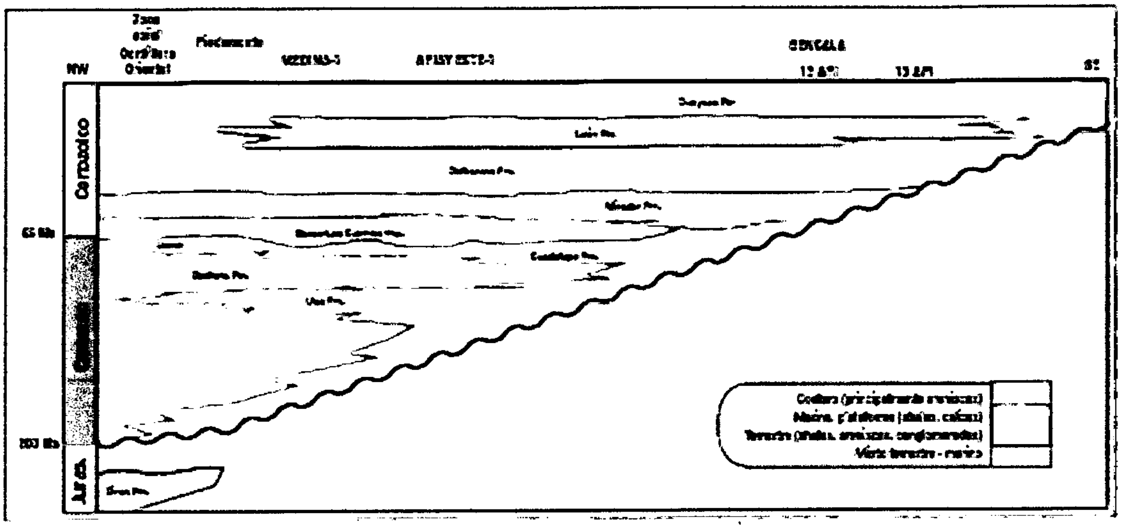


Figure 6. Structural and stratigraphic section showing geographical elements and limits of oil reservoir systems.

Reservoir rock

Reservoir rocks show a range between the Middle Cretaceous and Late Miocene associated to the Gachetá Cretaceous-Tertiary oil system (I); sand units, which include the Une, Gachetá, Guadalupe and Mirador units. Members C7, C5, C3 and C1 of Carbonera Formation (Figure 6) are oil reservoir rocks of the area. The most important oil reservoir rocks containing the greatest percentage of heavy hydrocarbons in Eastern Llanos are the Une Formation (Cretaceous) and member 7 of Carbonera Formation (Tertiary) with 57% and 24.5%, respectively, of known oil reserves.

Seal rock

For the whole basin, the argillite section of León Formation is deemed the regional seal for the Gachetá oil reservoir system (Figure 6). In the cretaceous section, the shale unit of Gachetá Formation is an effective seal for Gachetá-Une oil reservoir system, which includes 57% of heavy hydrocarbon reserves (395 MMBO P-10). The second regional seal is formed by the sequence of infra-formation argillites of members C-8 and C-6 of Carbonera Formation, which contains 35% of the heavy hydrocarbon volume stored in the oil reservoirs of Mirador and C-7 formations.

INTERPRETATION

Seismic interpretation summary

In the 2006 Heavy Crude Oil Project (PCP), 6140 kilometers of seismic data were interpreted. Approximately 4700 km of seismic is associated with the special area of ANH. In the 2008 Project for Development of Heavy Crude Oils, around 2200 km of seismic data were interpreted. They are located in the eastern zone of the basin.

Gravimetric and magnetometric interpretation

Figure 7 shows a map of Simple Bouguer anomalies. In the warm areas a sedimentary sequence can be interpreted of a thickness less than that found in the areas highlighted with light blue and green colors. It can be also shown a shallower basement in the first areas, as well as their deepening in the second areas.

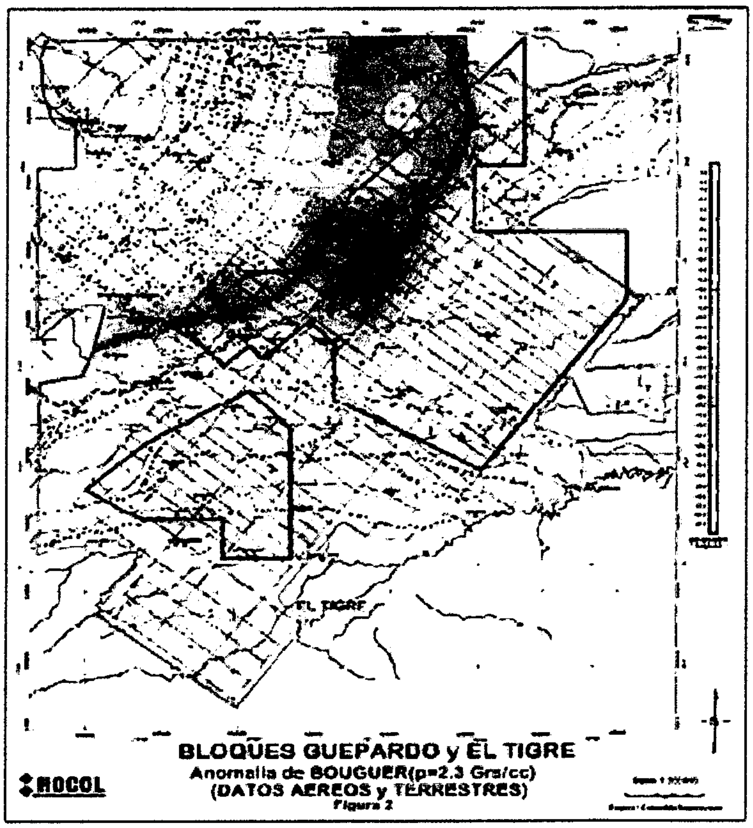


Figure 7. Map of Simple Bouguer Anomaly (P= 2.3) for Guepanto.

Oil field engineering and production

Hydrocarbon production in the area

Production fields in the Eastern Llanos Basin

The Eastern Llanos Basin in the eastern region of Colombia covers an approximate area of 220000 km^2. Geologically, it borders in the south with Vaupes Shelf or Guaviare Arch; in the east with the Guayana Shield; in the west with Eastern Cordillera, and in the north it reaches Venezuela, beyond the Arauca River.

Basin production comes from both Upper Cretaceous sandstones (Guadalupe Formation) and Lower Tertiary (Barco, Mirador and Carbonera formations). Its sedimentary cover involves sequences of Paleozoic, and Tertiary Upper Cretaceous. In the north, the Vaupes Shelf reached the Meta Sector. In the Meta Sector stands out the Apiay Block, where so far an accumulation of hydrocarbons in Upper and Tertiary Lower Cretaceous in Apiay-Guayuriba and Suria-La Reforma fields has been found. Casanare area is located in the very heart of the basin between rivers Meta and Casanare.

Heavy crude oil belt located in the east side of the gravity limit $^{o}API<20$, up to the approximate geographical limit of Gachetá-Mirador oil reservoir limit, goes from Apiay Field, includes Rubiales Field where it would reach between 80 and 100 km width and continues in the northeastern direction towards El Miedo Field where it converge the two limits of gravities $^{o}API<20$ and that of the Gachetá-Mirador oil reservoir system. In this zone have been detected wedgings and structural situations favoring hydrocarbon accumulation. There are wedgings in C7-C3 members of Carbonera Formation against the crystalline basement or against the Paleozoic in the eastern sector of the province.

Daily production is of 345377 BPPD, and an accumulated production of 3045 MMBls is available. Figure 8 shows production fields of the basin, it is worth to underline that Caño Limón, Cusiana, Cupiagua, Castilla and Rubiales fields represent 62% of the total production of the basin.

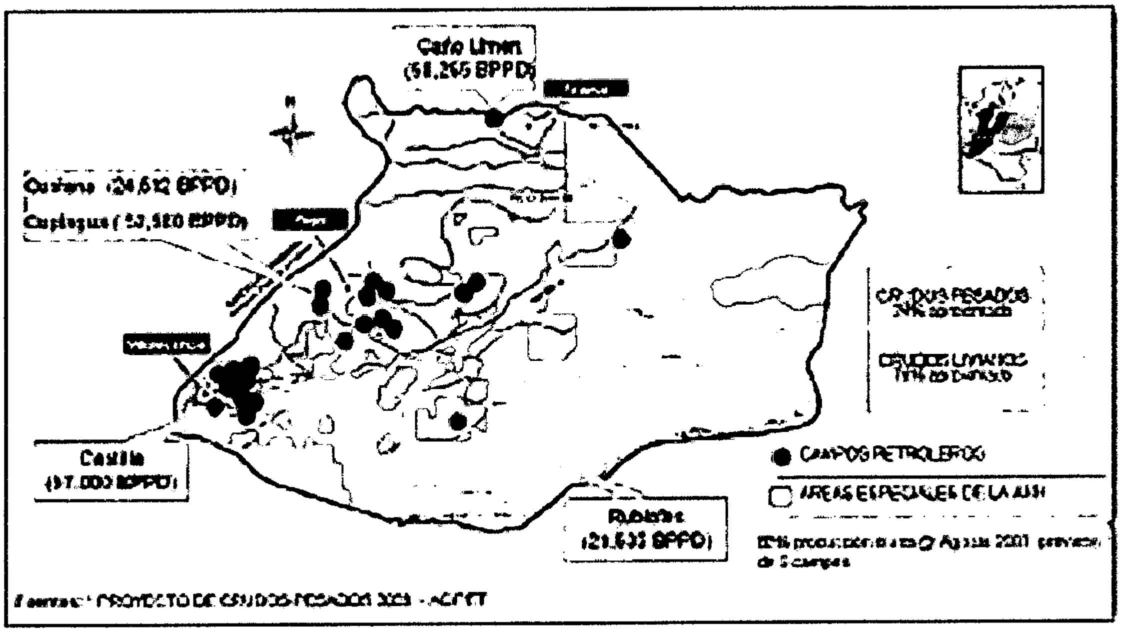


Figure 8. Most important production fields in Eastern Llanos Basin.

The Eastern Llanos Basin has today a 429 MMBl accumulated production of heavy crude oils and a daily 103000 BPPD production. Remaining developed proven reserves have been estimated to be 187 MMBO from September 1st 2007 for Eastern Llanos heavy crude oil fields. Possible reserves for fields producing heavy crude oil near the prospecting area of interest or special area are approximately 767 MBO.

Companies operating in the Eastern Llanos Basin

The excellent prospecting activity and productivity in the Eastern Llanos Basin has triggered the interest of at least 44 companies that are operating in approximately 13506931 ha, which is about 63% of the whole basin area.

Drilling activity in Eastern Llanos Basin between 2005 and 2007

Companies operating in the area drilled 263 prospecting and development wells between 2005 and 2007 (approximately 1525700 feet reported).

Prospecting wells with traces of hydrocarbons

59 out of 99 wells drilled between 1945 and 2000 showed traces of hydrocarbons, and 29 were dry. No data are available on the remaining 11 wells.

Oil infrastructure

Crude oil pipelines

We found crude oil pipelines with 6 to 36 inch diameters, and 5 to 559.9 KBPD capacity.

Gas pipelines

We found gas pipelines with 3 to 20 inch diameters and 4 to 100 KBPD capacity. Figure 9, shows the development of oil infrastructure in Eastern Llanos Basin.

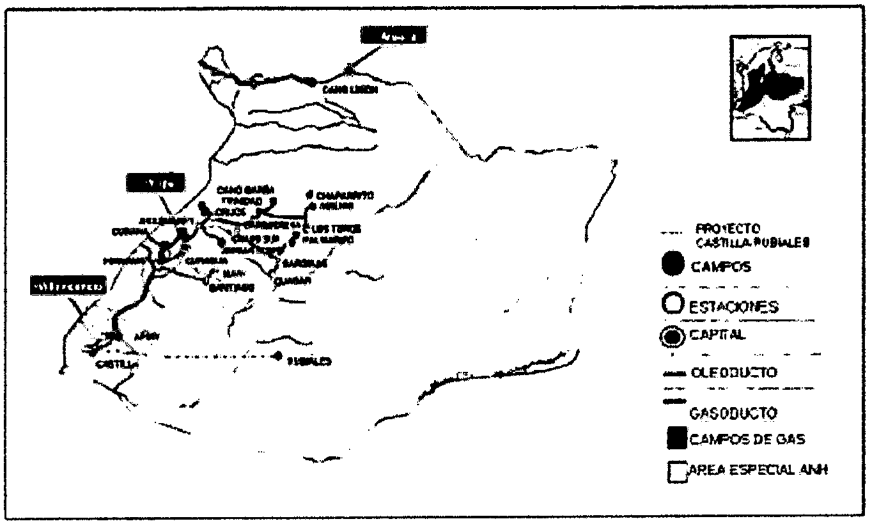


Figure 9. Oil Infrastructure Map – Easter Llanos Basin – Source: Study on Heavy Crude Oil Development 2007.

Estimate prospecting potential in the Special Area

Prospecting opportunities in Eastern Llanos Basin have been identified in the following reservoirs: Une, Guadalupe, Mirador, Carbonera C5-C3-C1. These are hydrocarbon-storing rocks prevailing in Eastern Llanos, although accumulations are not discarded in more argillaceous units, as really has happened in Gachetá Formation. To identify areas of interest, 8300 km of seismic lines covering Eastern Llanos Basin were interpreted.

The Miedo Lead case of Une Formation is given below as an example.

Miedo Lead:

This lead is located in the northeastern area of the basin, south of El Miedo Field (Figure 10). Its identification was based on interpretation of new seismic lines, which allowed obtaining a better precision in the pinching limit of Une formation against the Basement. Three areas were determined for the Lead with the purpose of making a probabilistic calculation of potential resources of hydrocarbons that could be obtained, to wit: a minimum area of 76593 acres, a medium area of 140064 acres and a maximum area of 193891 acres. Figure 11 shows the seismic line RT-1989-01, which belongs to one of the new interpretated lines, and shows the pinching of Une Formation against the basement. Location of seismic line can be seen highlighted with blue color in Figure 10.

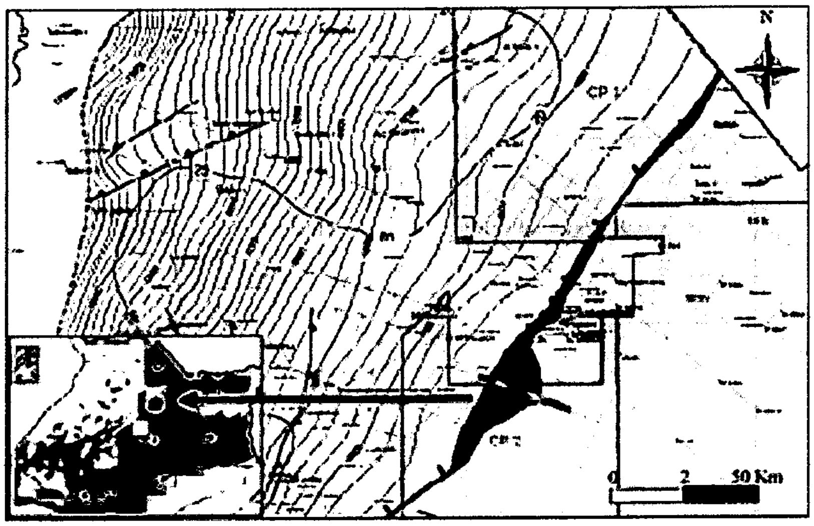


Figure 10. Geographical location of El Miedo Lead.

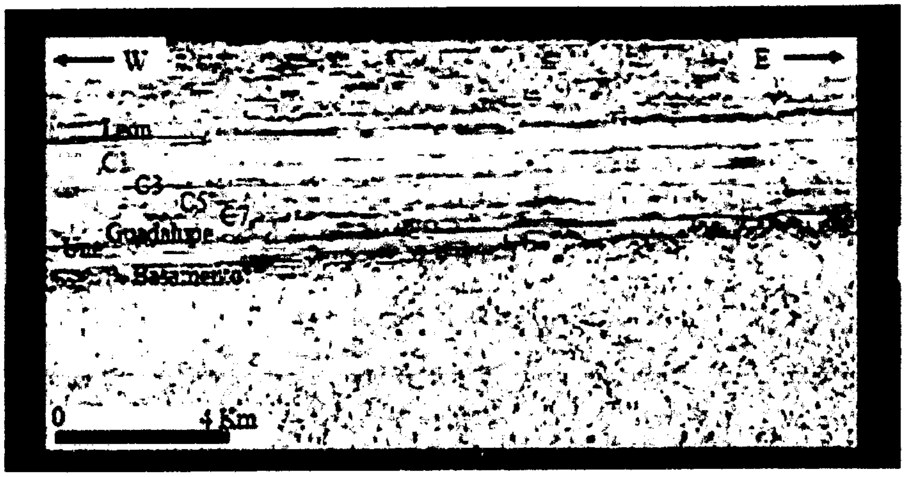


Figure 11. Seismic line RT.1989-01 showing pinching in Une Formation against the basement.

The Une Formation is featured as a massive packet of sand, which specifically shows for this lead a total thickness ranging between 10 ft and 130 ft, according to the petrophysical maps prepared in the work PCP 2006, and for nearer wells such as Dorotea-1 Well (Figure 12). Net sand thickness was obtained from those intervals, achieving a percentage lower than 30% of clays and 10%-40% effective porosity. In this case we have a net sand thickness ranging between 10 ft and 100 ft with a more probable value of 60 ft.

The porosity values were taken from the petrophysical maps of the work PCP 2006, which vary from 0.23% to 0.3% with a more probable value of 0.25%, and the oil saturation was taken from the nearest wells, which have or had production at this level such as the Jordan-1 Well. These values range between 0.72% and 0.8% with a more probable value of 0.75%.

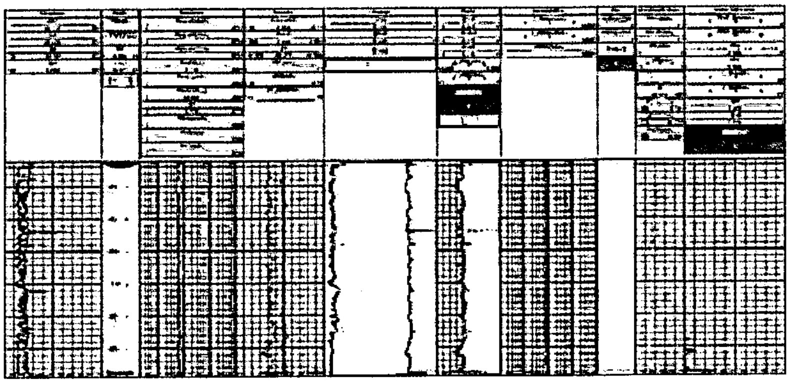


Figure 12. Petrophysical interpretation of Dorotea-1 Well, showing massive sandstones of Une Formation.

CONCLUSIONS AND RECOMMENDATIONS

- The present study concludes that this is a highly prospective area with 135 successfully proven fields currently producing 350.00 BOPD.
- The area has been divided into eight blocks in the eastern sector and 17 in the western sector. Both areas offer a great prospecting interest owing to evidences these areas present, and to their proximity to the Venezuelan Basins.
- The fact is that the eastern sector is becoming a potentially producing area of heavy crude oils whose evidences have been reported in several wells under exploration process where some investments are required for acquiring information and infrastructure, which represent an important challenge for the Colombian government, ECOPETROL, ANH and private investors.
- The western sector is surrounded by several producing fields and prospecting wells with traces of hydrocarbons, and has a great civil and oil structure.
- Although the basement seems to emerge toward the end of the eastern basin, it is very important to gather information to prepare basement cartography with better level of reliability and determine, which new exploratory prospects can result between the Rubiales Field and the basin border because it is possible they can find new structures, as new information is gathered in the eastern sector.

REFERENCES CITED IN THE ORIGINAL WORK

Instituciones Consultadas

1. ANH – EPIS. Ministerio de Minas y Energía - Subdireccion Nacional de Hidrocarburos

Informes Técnicos del 2006 de los campos actualmente productores de crudo pesado

Listado de los pozos que están dentro del área especial de la ANH

Formas 9SH de todos los campos presentes en la cuenca Llanos

Coordenadas de los 47 campos que faltaban por ubicar en el mapa

2. Ministerio de Transporte

3. ECOPETROL - Vicepresidencia de Exploración

4. INGEOMINAS

5. IGAC

6. Direccion Nacional de Parques Nacionales

7. Parques Naturales de Colombia

Información suministrada por la ANH

1. Información correspondiente a los contratos de exploración y explotación: • Caño Sur Primera Fase • Caño Sur Segunda Fase • Caño Sur – Proyecto Desarrollo de Crudos Pesados

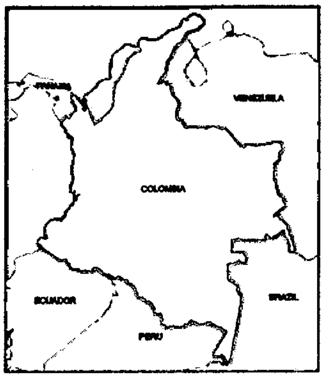
2. Folleto geológico y petrofísico Hadas 1.

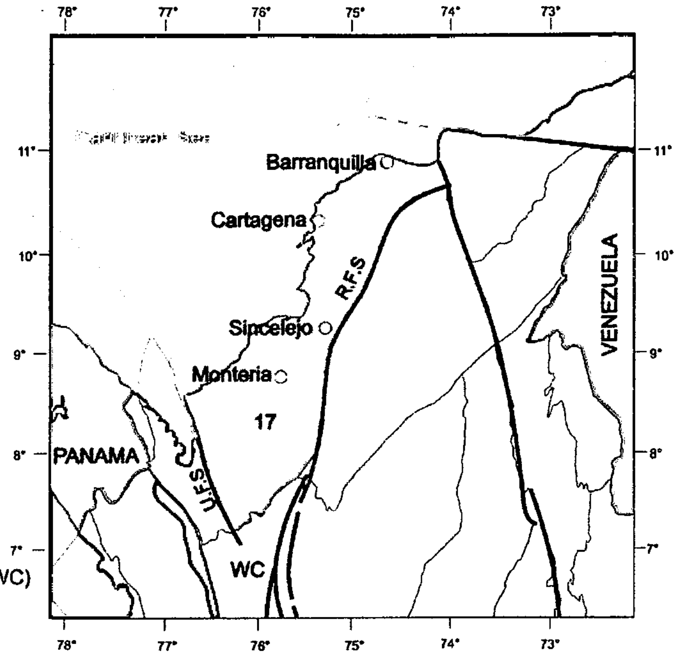
3. Informe Ejecutivo Técnico anual 2005.

6. SINU – SAN JACINTO BASIN

The Sinú-San Jacinto Basin is located in Northern Colombia and is the most prolific area in oil and gas seeps among Colombian basins. This under-explored basin limits to the east with the Romeral fault system; to the north-northwest with the present Caribbean coast; to the west with the Uramita Fault System, and to the south with the cretaceous sedimentary and volcanic rocks of the Western Cordillera (Figure 1). The structural development of the basin is linked to the transpressional deformation generated by displacement of the Caribbean Plate. The Sinú portion of the basin is very rich in mud diapirs and oil seeps.

SINÚ - SAN JACINTO BASIN
LOCATION AND BOUNDARIES

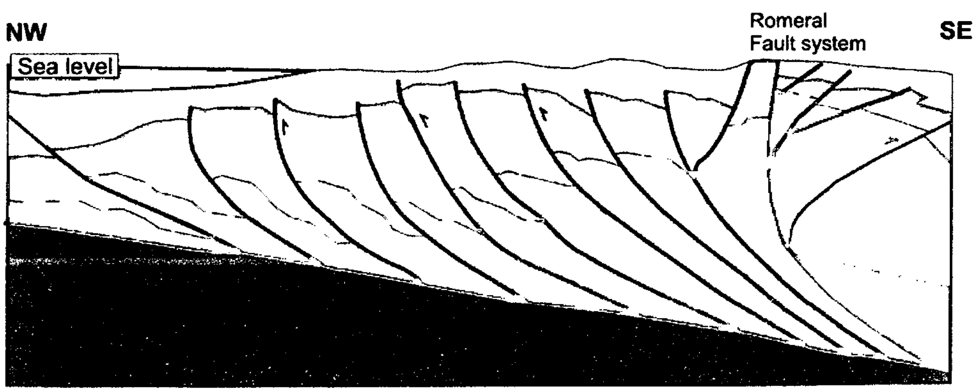




BOUNDARIES

North- northwest: Present Caribbean coast
East: Romeral fault system (R.F.S.)
South: Cretaceous rocks of the Western Cordillera (WC)
West: Uramita fault system (U.F.S.)

SCHEMATIC CROSS SECTION
SINÚ - SAN JACINTO BASIN



Color code according to the commission for the Geological Map of the World (2005)

Oceanic Crust | Continental Crust | Paleogene | Neogene

Figure 1. Sinú – San Jacinto Basin.

GEOLOGICAL CARTOGRAPHY IN THE AREA OF THE SINU-SAN JACINTO FOLD BELTS[1]

B&G UNIÓN TEMPORAL

2006

SUMMARY

The results obtained from the the Sinu – San Jacinto Fold Belts Geological Cartography Project in the Colombian Caribbean are presented. The project involved the geological cartography of the Luruaco Block (390 km^2) where a ninety kilometers of geological transects, of which forty were aimed to obtain structural data and fifty to acquire basic geological data for the construction of the geological map, were followed. The structural analysis associated to this report is supported by four admissible structural sections, fundamentally constructed on the basis of data obtained in the field. The sections were not retro-deformed because this is a transcurrent tectonic environment, where an exercise in two dimensions does not provide reliable solutions.

The stratigraphic survey and systematic sampling of the Luruaco, Arroyo de Piedra, Pendales formations, and their respective analyses add up to 1841 m of stratigraphic column.

In the San Jacinto Block (Cansona Hill), located to the west of Carmen de Bolívar municipality, a stratigraphic column of the Cansona and San Cayetano formations was surveyed. The stratigraphic analysis and the systematic sampling along 923 m of surveyed area, form an integral part of this report.

[1] Cartografía geológica en los Cinturones Plegados Sinú- San Jacinto. Producto: Compilación, análisis y evaluación de la información existente. B&G Unión Temporal. Bogotá D.C., Marzo, 2006.

Finally, sixteen sites with hydrocarbons seeps were visited. Samples of some of them were taken and sent to the ICP (Colombian Institut of Petroleum) in Piedecuesta, Santander Department. Samples of rock extracted during this work were also sent according to the required delivery protocols.

OBJECTIVE

The purpose of the project was basic geological cartography at a scale of 1:25000 with structural analyses, rock and fluids samplings and the stratigraphic columns survey at a scale of 1:200 in the areas of the Sinu-San Jacinto Fold Belts.

LOCATION

The Luruaco Block is located in Bolívar and Atlántico departments, specifically in Santa Catalina and Villa Nueva municipalities in Bolívar Department and El Arenal, Repelón and Luruaco in Atlántico Department. The surface area of the block is 390 km^2 (Figure 1).

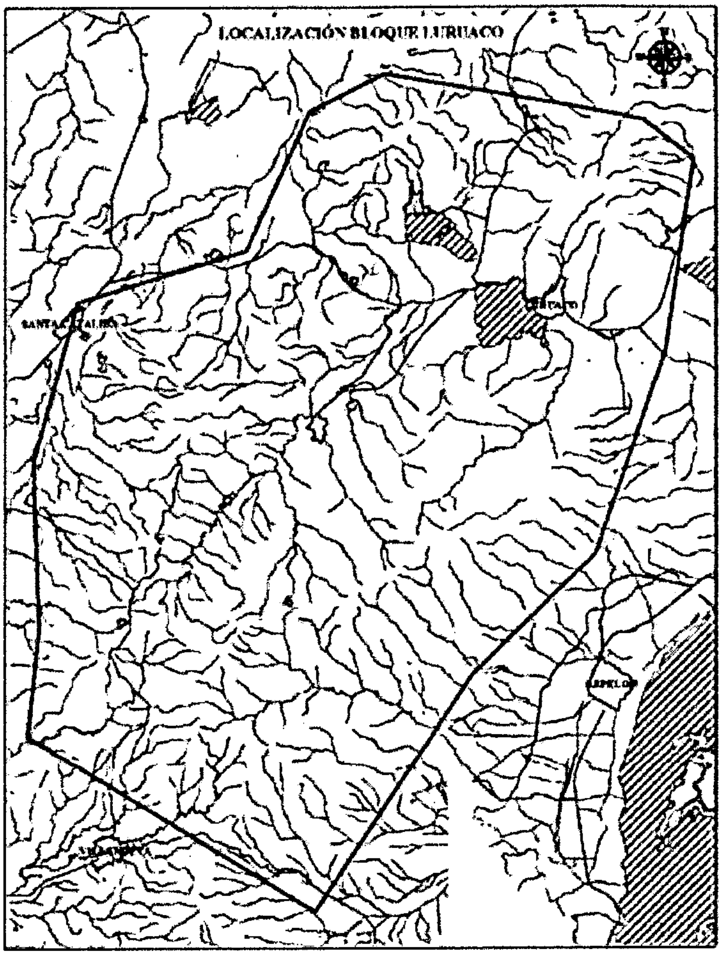


Figure 1. Location of the study area.

METHODOLOGY

Phase I: Compilation, analysis and evaluation of the existing information, photo-interpretation and preparation of the photo-geological map of the Luruaco Block.

Phase II: Field geology. For the description of the different types of sedimentary rock, in both the transects and the stratigraphic columns, the Dunham (1962) and Folk (1959) methodologies were followed for the calcareous and siliciclastic rocks, respectively. For the compositional classification, Folk, 1974 was followed. The Dott (1964) maturity concepts, the Folk (1959) and Krumbein & Sloss (1963) scale of sizes for calcareous rocks and the Powers (1953) roundness classifications and calibration were applied. The letter edited by the Geological Society of America (1991), was used as a descriptive aid for rock color definition. The considerations of Campbell (1967), among others, and the degree of bio-disturbance were used to establish the thickness of plates and layers.

Phase III: Preparation of the final report and editing of maps and figures. The data are shown in Bogotá datum flat coordinates.

Phase IV: Presentation of the Final Report with its respective Annexes.

Tectonic Framework

The greater part of the deformation in the San Jacinto Fold Belt was concentrated in a strip located between the Romeral Faults System and the Sinú Frontal Folds and Thrust Faults. The formation of the thrust faults with opposed vergences on the eastern and western flanks of the Luruaco-San Jacinto Anticline are responses to episodes of a transcurrent nature. In general, the development and geometry of the subduction suggests a basically directional dominion in the deformation of the pre-Pliocene and a deformation from the Pliocene to recent, dominated by a combination of movements in a right and inverse lateral direction throughout the length of the Romeral Faults System.

Gravity data for Colombia show that the lithospheric flexure does not represent an important mechanism in the development of the Sinú and Lower Magdalena Valley basins. According to this, the thin cortical layer under the Sierra Nevada de Santa Marta suggests the existence at relatively superficial depths of the Moho discontinuity. In this sense, the massif constitutes a positive Bouguer Anomaly, whose pattern suggests the absence of a deep cortical root, where the topographic load is related to an important flexure of the South American and Caribbean lithospheres. It may be inferred that the interaction between the Caribbean and South American plates in the Colombian Northwest has formed a structural style typical of transcurrent systems, which, in turn, have controlled basin formation processes such as those of the Lower Magdalena Valley and Sinú.

Geology of the Luruaco Block

A lithological description of the litho-stratigraphic outcrops in the Luruaco area was made indicating, in its turn, their geographical distribution, mapped at a scale

1:25000. The described units are the product of the survey of four cartographic and four structural transects, giving a total of 90 linear kilometers, with geological data that demarcate units, which may be mapped.

Five geological units were identified: the Luruaco Formation (E1L), formed in this region by three clearly differentiable members informally referred to as lower, middle and upper members; Arroyo de Piedra Formation (E2Ap); Pendales Formation (E2P); El Carmen Formation (E3C); Rotinet Formation (QaR) and Others quaternary deposits (Qal).

Structural Geology

The structural analysis of the Luruaco Block was supported by the information obtained from the survey of four structural and four cartographic sections, which are distributed nearly perpendicular to the regional train of the Luruaco-San Jacinto Heights. These sections allow a reliable visualization of the elements making up the geometry and the dominant structural styles in the area.

Description of Structural Sections

The integration and analysis of geological information from different sources, including the surface geology acquired during this photo-geological study, as well as regional considerations, provide the basis for the preparation of a series of four admissible structural sections. Structural interpretation is founded, in particular, on the field data collected during this campaign, complemented by a geometrical analysis and structural modeling. The sections characterize the surface and subsoil structure and are considered to be admissible sections. The absence of subsoil information, in addition to a lateral deformation component whose displacement magnitude is unknown, and the short length of the sections are factors, which limit a reliable restoration and this is not included in the sections.

An integral analysis of the surface geology, the structural interpretation, and regional aspects make possible to recognize an association of distinctive structural elements, which typify the structural style of the study area. This includes: the presence of pop-up structures in high structural relief controlled by deep faults of opposite vergence. The presence on the surface of segments of faults, locally with echelon geometry, and the large scale surface configuration of the structure is a characteristic of the study area. All these are typical aspects of a structural style associated with transcurrent or wrenching systems.

In the study area, the Luruaco anticline is a characteristic of a pop-up structure controlled on its flanks by faults or systems of faults at a moderate to high angle and opposite vergence. The structure is nucleated by the lower section of the Luruaco formation and older rocks, possibly with some associated mud diapirism. The structural configuration of the anticline is controlled significantly by the architecture and configuration of the in depth structure.

Stratigraphy

As a result of this work, 920 m of stratigraphic columns at a scale of 1:200 for the San Jacinto Sector and 1420 m of stratigraphic columns at a scale of 1:200 for the Luruaco Area are presented. Rock samples were taken from each sector for a variety of analyses, as well as records ofGamma Rays.

The results of references, location, litho-stratigraphic description, thickness, contacts and correlations, litho-facial description, facial association, facies and age analysis for the San Jacinto Anticline (Cansona and San Cayetano formations), the Luruaco Anticline (Luruaco, Arroyo de Piedra and Pendales formations) are presented.

As an example, Figure 2 shows a stratigraphic column of the San Cayetano Formation.

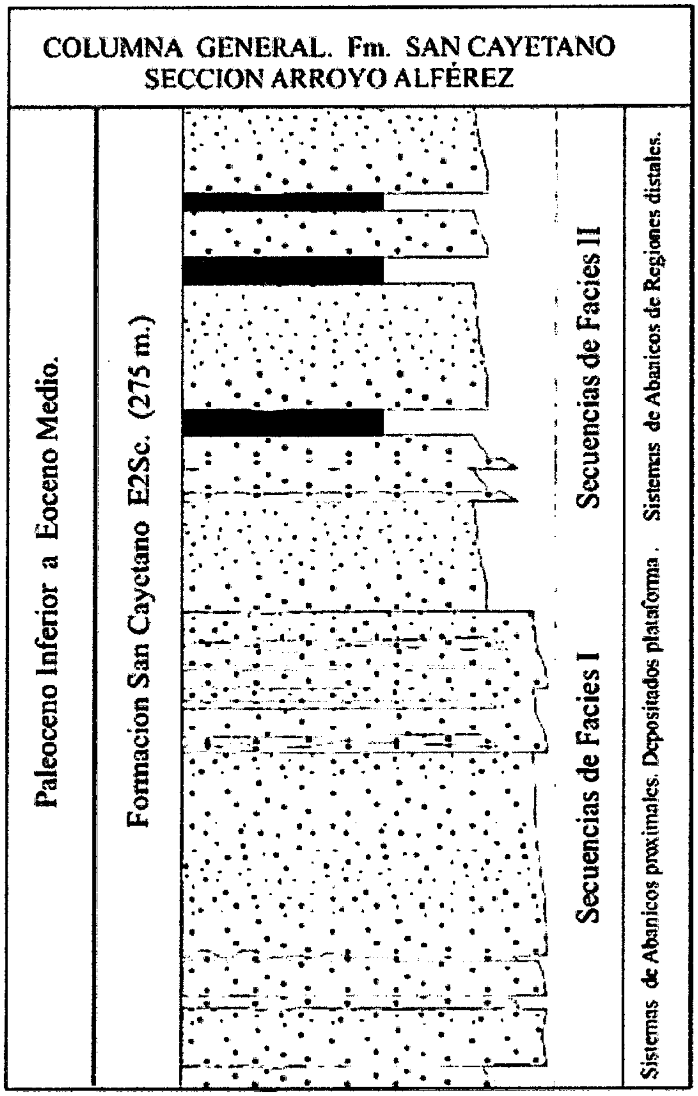


Figure 2. Stratigraphic column of the San Cayetano Formation.

Figures 3 and 4 show the generalized stratigraphic columns of the formations surveyed in the San Jacinto and Luruaco anticlines.

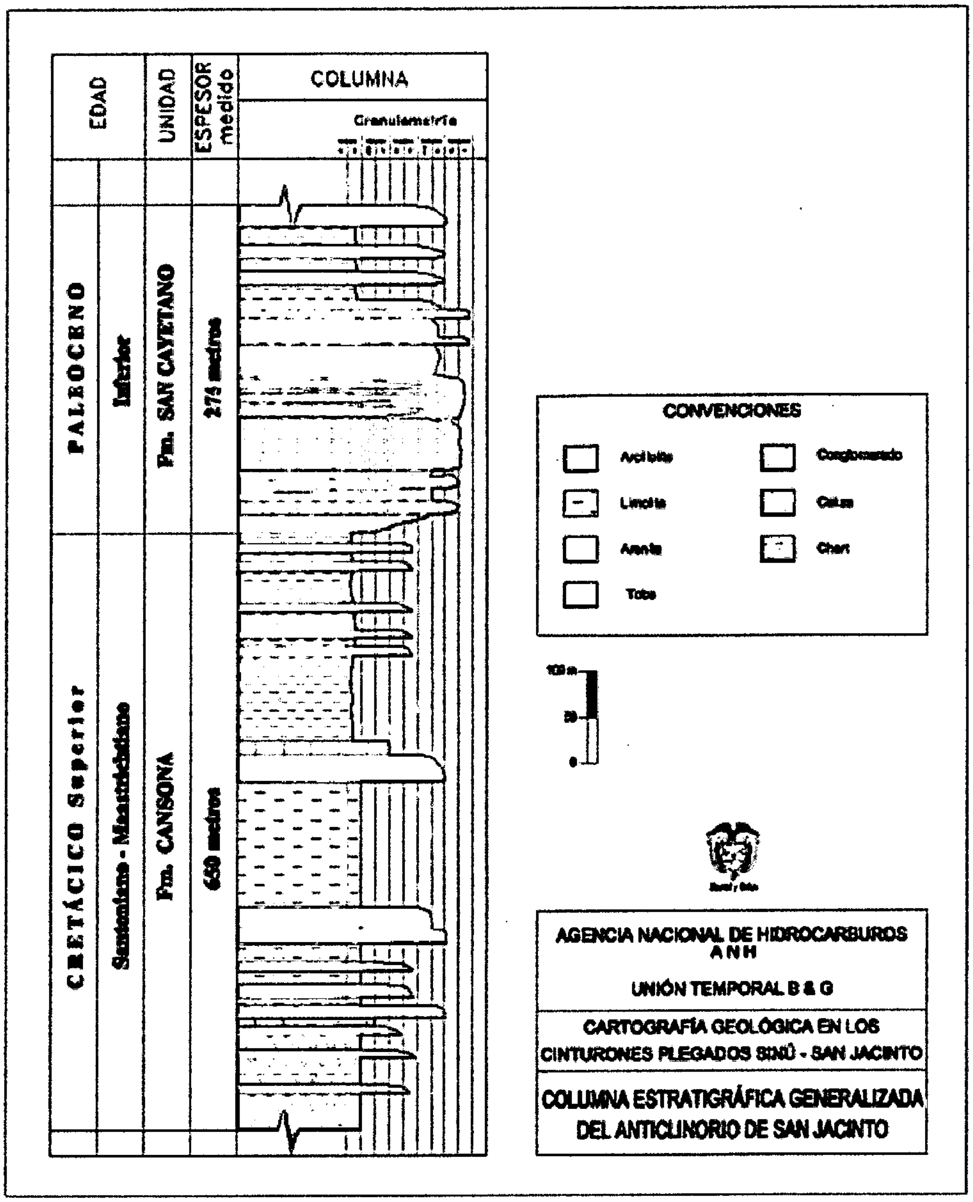


Figure 3. Generalized stratigraphic column of the formations surveyed in the San Jacinto anticline.

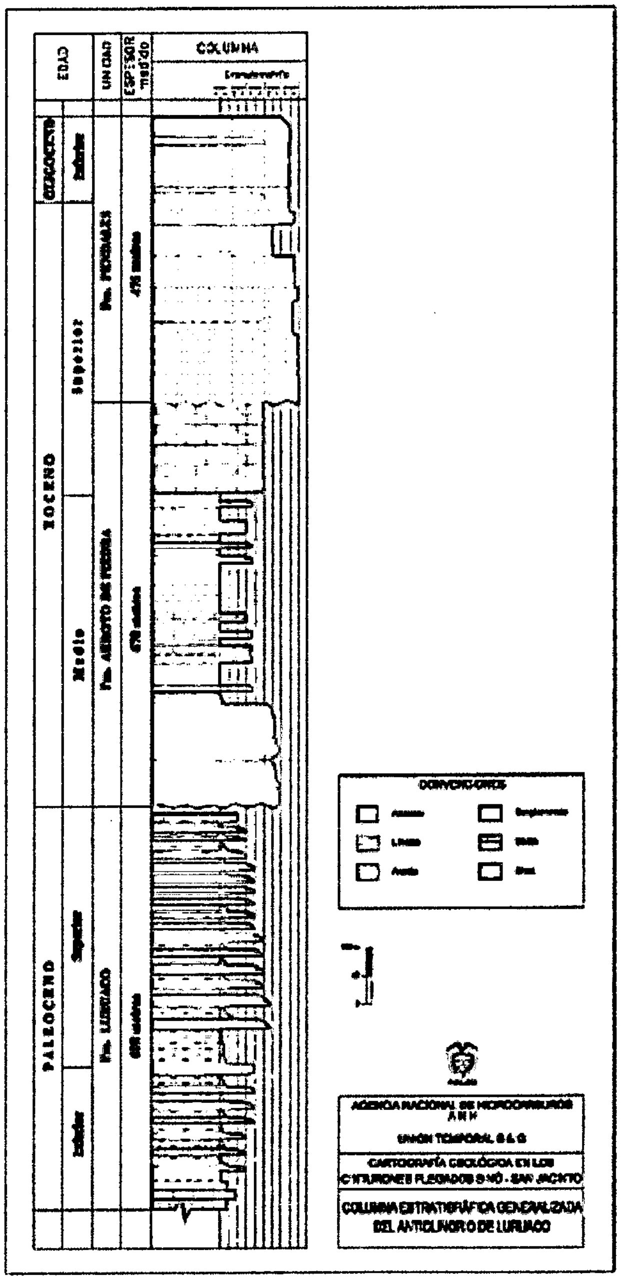


Figure 4. Generalized stratigraphic column of the formations surveyed in the Luruaco anticline.

Evolution of the Caribbean Basin

The geological evolution of the Caribbean Basin took place during of the late Cretaceous, and resulted because of an interaction between the South American and Caribbean plates. At the end of the Cretaceous, there were two great geological dominions: to the east of the Romeral Seam there was an emergent zone, probably the continuation of the Central Cordillera to the north, formed by sedimentary volcanic rock with low degree regional metamorphism. To the west, a basement of oceanic affinity rocks formed by basalts and serpentinites apparently produced in a center of oceanic expansion and of late Cretaceous age. From the late Cretaceous to the early Neogene, the Pacific Plate began a continuous movement to the northeast throughout the length of a zone of NE-SW direction faults. Thus, the emplacement of the Western Cordillera, and the basement of the Caribbean Basin (Sinu-San Jacinto terrains) along transcurrent faults took place.

CONCLUSIONS

- From the structural point of view, the Luruaco Anticline and associated structures are characteristic of a transpressive structure.
- The total displacement in the direction is unknown and very possibly its indicators are outside the block.
- Regional observation and structural configuration suggest a left lateral movement as the primary deformation mechanism.
- The presence of syntectonic deposits associated with the Arroyo de Piedra and Pendales formations show the structural development of the area. They suggest the pre-Miocene age of the beginning of the structure, later raised and exposed by more recently deforming processes of the Plio-Pleistocene.
- Geomorphological and stratigraphic evidence, such as the dynamics of the Magdalena River, show the changes undergone by its bed in recent historic times. The ancient alluvium materials found at heights of more than 100 m above the present base of the River Magdalena lead us to suppose that the rise undergone by the Luruaco ridge is recent and that it influenced the displacement of the present riverbed.
- The lateral changes of facies of the paleogenic sedimentites in the Sinu-San Jacinto Fold Belt restrict optimal mapping surveys in the area. Consequently, for future geological campaigns, we suggest a rigorous biostratigraphic study to establish the correlations and define reliable ratios between the stratigraphic units and sequences.

- It is not unusual to find cataclastic foliations at the muddy levels close to the shear zone of major faults parallel to the stratification, demonstrating the differential response of the different types of strata to the shearing caused by the faults.
- The Cansona Formation sedimentites represent the oldest stratigraphic unit on the Sinu-San Jacinto Fold Belt.
- The stratigraphic cycles of the Maastrichtiano and Paleogene of the San Jacinto-Luruaco Blocks show a progressively shallower basin.
- The facial characteristics of the Cansona Formation are indicative of a deep marine environment towards the external platform, while the San Cayetano Formation has characteristics related to an internal platform.
- The Luruaco Formation sedimentites are predominantly platform deposits.
- The Arroyo de Piedra calcareous facies are related to environments from intertidal to supratidal environments.
- The Pendales Formation is indicative of fundamentally fluvial conditions with a high energy current and low sinuosity.
- From the oil prospecting point of view, the element of greatest impact is the risk in synchronism or the ratio between the generation pulsations and trap formation.

REFERENCES CITED IN THE ORIGINAL WORK

Cambell, C. V. (1967). Lamina, lamina set, bet, and betset: Sedimentology, v. 8, pp. 7-26.

Dott, R. H., JR. (1964). Wacke, graywacke, and matriz-what approach to inmature sandstone classification? Tour. Sedimentary Petrology, v. 34 pp. 625-632.

Dunham, R. J. (1962). Classification of carbonate rocks according to depositional texture, p. 108-121 in Ham, W. E., ed., Classification of carbonate rocks: Tulsa, OK, American Association of Petroleum Geologists Memoir 1, 279 p.

Folk, R, L. (1959). Practical petrography classification of limestone: American Association of Petroleum Geologists Bulletin, v. 43, pp. 1-38.

Krumbein, W, C. & Sloss, L, L. (1963). Stratigraphy and sedimentation: W. H. Freeman, San Francisco, 660 p.

Power, M. C. (1953). Anew roundness scales for sedimentary particles: Tour. Sedimentary Petrology, v. 23, pp. 229-234.

GEOCHEMICAL SURFACE SURVEY SINU-SAN JACINTO BASIN[1]

HIDROGEOLOGÍA, GEOLOGÍA, AMBIENTAL LTDA – HGA LTDA.

2006

INTRODUCTION

The sampling of canned gas in free space is one way of analyzing volatile compounds linked to a sample without the use of extraction by solvents. The term "headspace" refers to the free space between the upper part of the liquid or solid content and the lid of a tin can. This technique is usually referred in the pharmaceutical ambit as headspace gas chromatography, and the objective is to analyze the vapor of the substance present in the space between the level of the liquid (or solid) and the lid of a tin can.

OBJECTIVE

Acquisition of 400 soil samples and processing by headspace gas chromatographic analysis with the purpose of detect and quantify light gases present in them.

LOCATION

The sampling area is located in the Bolívar Department, and it is surrounded within the polygon with coordinates that are presented following on Table 1.

---

[1] Estudio geoquímico de superficie. Cuencas Cesar-Ranchería y Sinú-San Jacinto. Hidrogeología, Geología, Ambiental Ltda. Abril, 2006

Table 1. Polygon of the sampling area.

Vertex	North (m)	East (m)
P1	1682614	880106
P2	1679321	895556
P3	1642848	886691
P4	1626385	914046
P5	1590165	905434
P6	1613119	841492
P7	1642435	843186
P8	1665648	850935

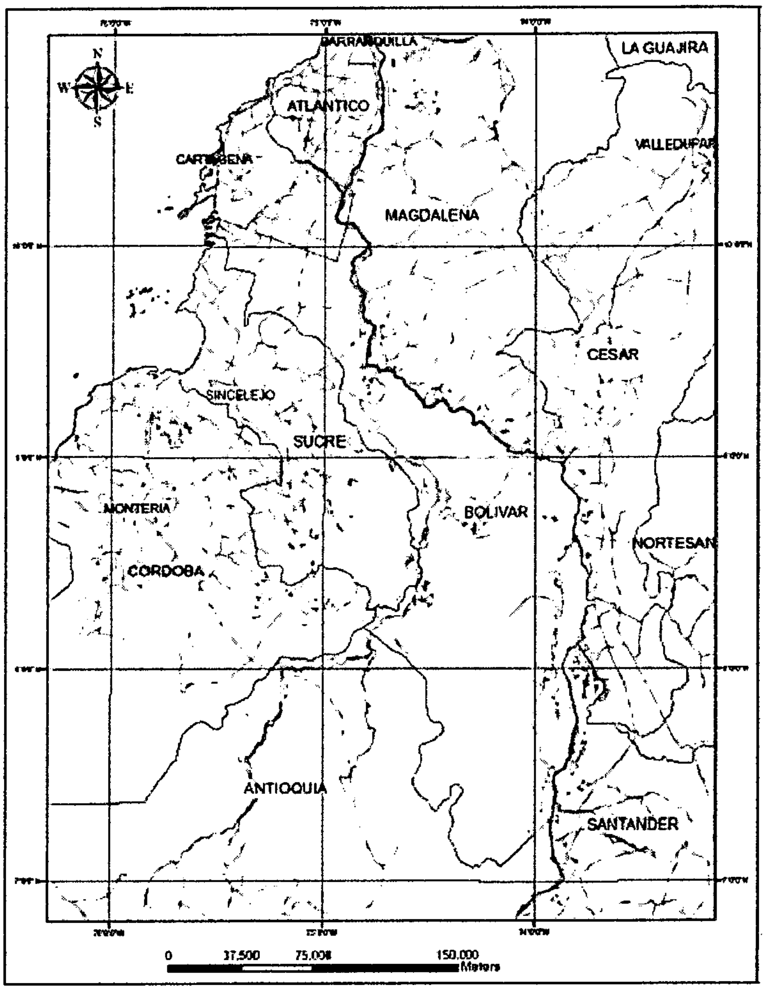


Figure 1. Location of the study area.

METHODOLOGY

The steps followed during the acquisition, processing and interpretation of geochemical data are presented as follows:

1) Sampling

- It was started from a sampling grid designed based on previous geological studies, which define structural characteristics having possible exploratory interest. In the study area 10 lines were programmed, 9 in E-W direction and 1 N-S direction. The principal structures and geological faults in the study area were considering because of their possible contribution to the emission of gases. The distance between the sampling lines is approximately 2 km and the spacing between the sampling points, at each line, is 500 m.
- From this grid, having the location of the sampling points, it was proceeded to consecutively enumerate the sampling points, naming the first point TL-1, and so on until the last sample (TL-400). Latter on, it was proceeded to the reading of the Bogotá origin coordinate of each point. A listing of coordinates was generated with which latter on, daily, was loaded each GPS, according to the points assigned to each geologist for field sampling.
- Before starting the sampling, a stage of area recognition was carried out with the purpose of designing the sampling strategy according to the accesses. This was done in order to obtain the corresponding permits to have access to the properties involved in the sampling, to hire auxiliary personnel and vehicles and to choose the base sites.
- A manual auger was used for the drilling of holes, which have depth between 0.80 and 1.50 m and are approximately 15 cm in diameter. The end depth of the hole is determined by getting to the fresh soil layer, which allows taking the no-contaminated sample, such as possible organic matter from the upper part.
- At each sampling point, approximately 250 g of soil was gathered and put into a tin can with a perforated lid. Before closing the tin can, the sample was diluted in water, filtered and preserved by way of a bactericide in order to avoid microbial degrading of the gases. With the same characteristics, an additional sample or safety countersample was taken, in case it would be needed to repeat the analysis or for an additional special analyses.

2) Data processing

- Chromatographic analysis of 400 samples of gas obtained from soil samples.
- Determination of the composition of said gases and quantify their concentration.
- Determination of the genesis of methane through analysis of carbon isotopes.

3) Interpretation

- Revision of results on the data table.
- Determination of Bernard's humectation index, and estimation of the type of hydrocarbon (biogenetic/mixture or thermogenetic).
- Filtering of database.
- Statistical treatment.
- Determining of the depth constant, and of first and second order anomalous values for each one of the gasses (C1 to C5).
- C1, C2, C3, iC4, nC4, iC5 and C5 gas cartography and overlying of C2 - C5 gasses.
- Evaluation chromatographic profiles.
- Cartography and description of areas of interest.
- Determining and plotting of relations.

RESULTS

Chromatographic analysis

For this analysis, a Hewlett Packard series 5890 II chromatograph was used, equipped with a flame ionization detector (FID) and one PLOT capillary column, having a stationary stage of alumina of 50 m length and a 0.53 mm inside diameter.

The *ChemStation* program receives and integrates the signal sent from the gas chromatograph, identifies and quantifies the concentration and shows a graphic representation of the results (chromatogram). The light hydrocarbons in the sample (methane, ethane, propane, acetylene, isobutane, butane, isopentane, pentane and hexane) were quantified according to a certified standard. The equipment was calibrated every 15 samples, and a blank sample was run every 10 analyses. The data obtained from the chromatographic analysis were organized in tables, which were used for chromatographic profiles and interpretation. The interpretation took into account the following:

Determining of the background constant and anomalies was carried out based on statistical treatment. The obtained values are shown on Table 2.

Table 2. Values of anomalies.

Gas	Mean	Standard Deviation	2nd order Anomaly	1st order Gas anomaly
	μ	σ	$\mu + 2\sigma$	$\mu + 3\sigma$
Methane	13.65	7.16	27.97	35.13
Ethane	1.67	1.10	3.87	4.97
Propane	0.44	0.38	1.19	1.57
Acetylene	0.04	0.14	0.33	0.47
Isobutane	0.18	0.71	1.61	2.33
Butane	0.41	0.39	1.19	1.58
Isopentane	0.06	0.18	0.41	0.59
Pentane	0.13	0.20	0.54	0.75
Hexane	0.07	0.35	0.78	1.13

Once the background constant and the grade of the first and second order anomalies were defined, contour and classes maps for all the thermogenetic gasses were elaborated. Figures 2, 3 and 4 show examples of the obtained maps:

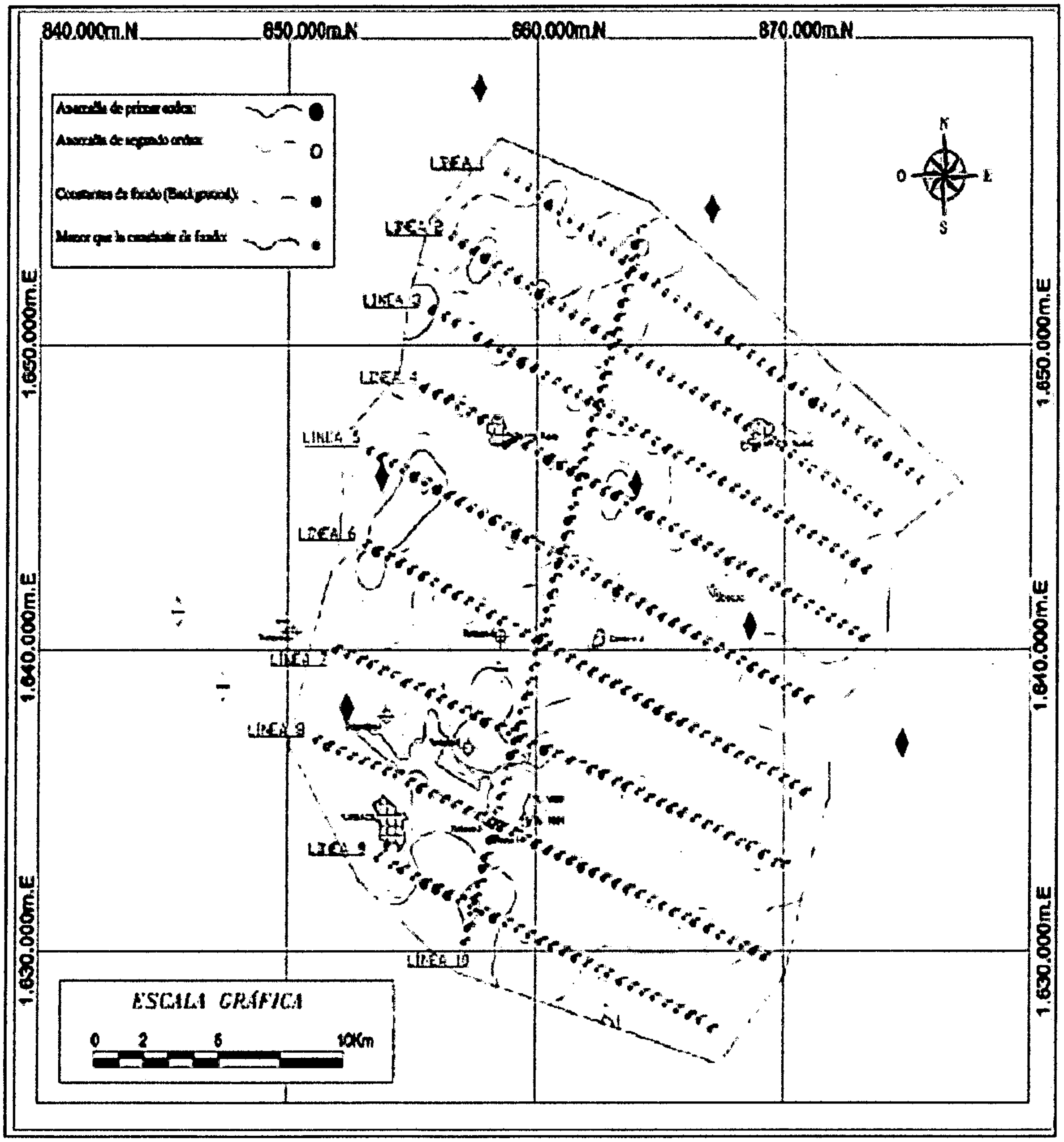


Figure 2. Map of clasess and contours of metane.

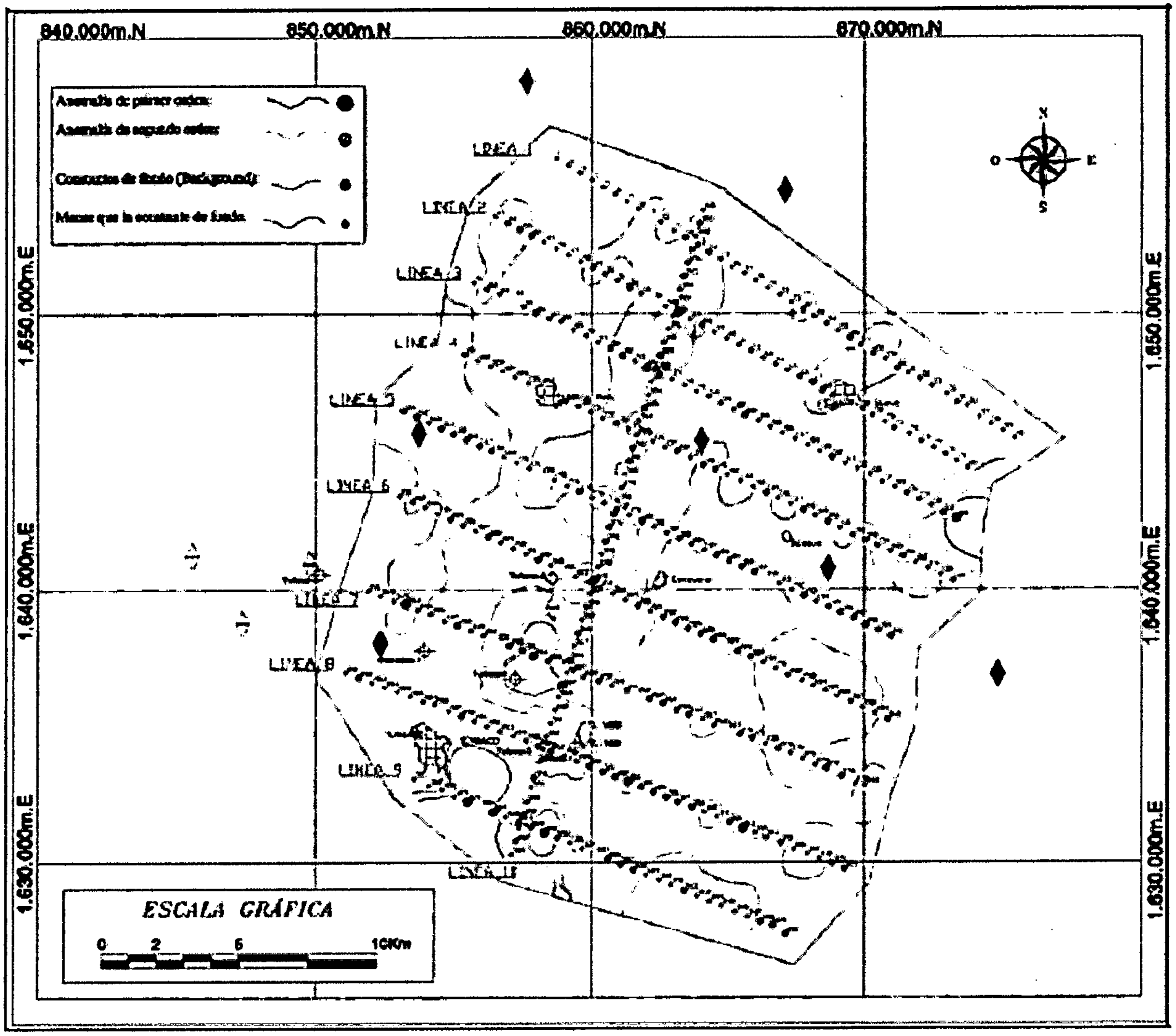


Figure 3. Map of clasess and contours of ethane.

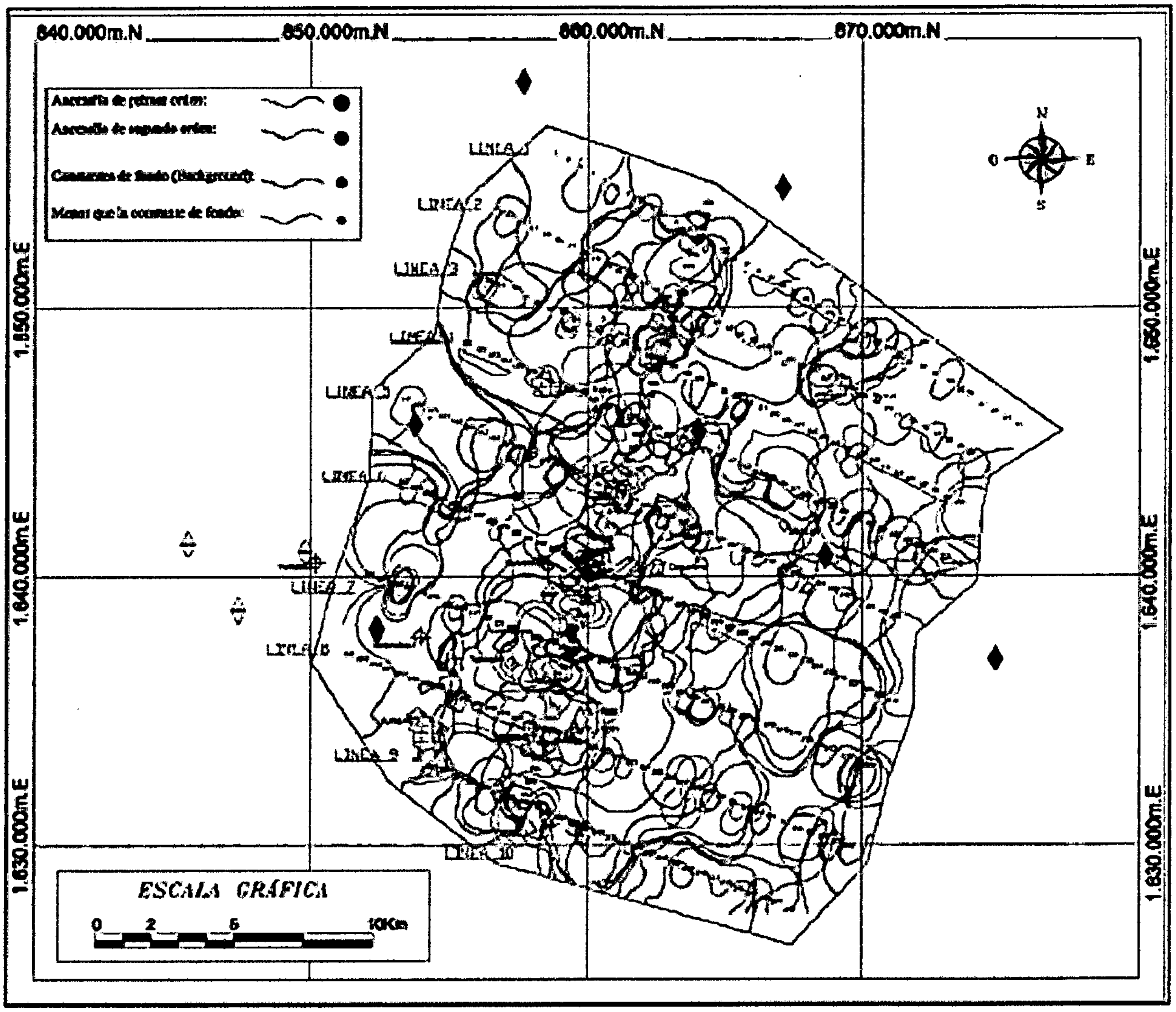


Figure 4. Map of supeposition of C2 to C5 contours.

The interpretation of the chromatographic data of the soil gas samples, evaluated in the present study, allows to identify 3 sectors of interest because of the presence of groups of geochemical gas anomalies of first and second order (Figure 5).

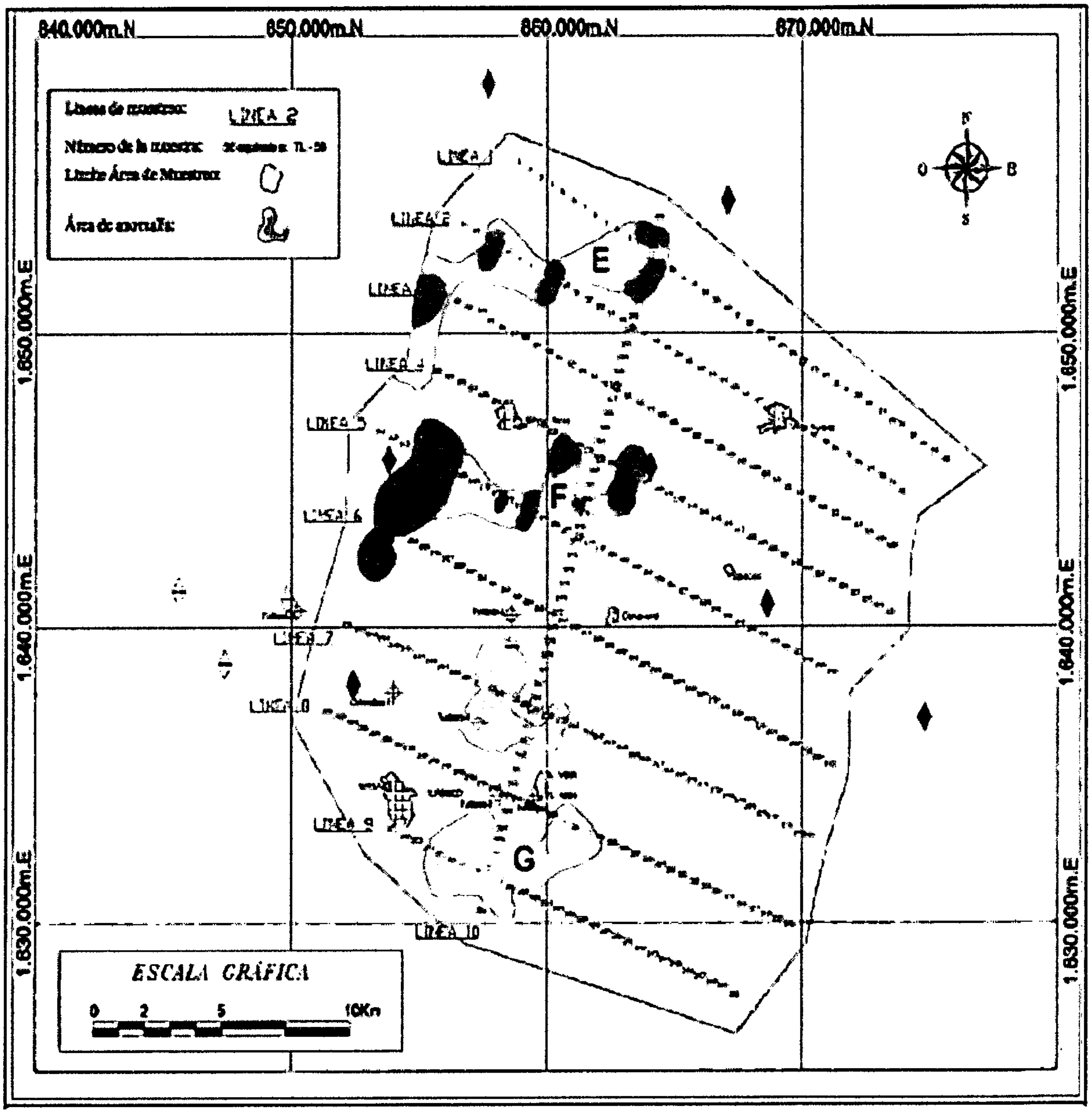


Figure 5. Map of areas of interest

Hydrocarbons Origin

According to Whiticar (1994), the relative proportion of C1 - C4 saturated alkanes within a gas sample, provides an initial classification of the origin of gas. Bernard (1978), uses the C1/(C2 + C3) ratio for describing the humectation ratio, amongst others, of the surface emanation gasses and sediments, and to estimate their origin (Table 3).

Table 3. Ratio. Bernard's parameter.

Ratio (Barnard's Parameter)	ORIGIN			
	Biogenetic	Mixture	Diagenetic	Thermogenetic
C1/(C2+C3)	>1000	100 - 1000	50 - 100	0 - 50

By applying this ratio, 5 (1.5%) samples, amongst the total of the 400, were identified, distributed as follows: 2 samples of gas (0.5%) of possible mixture and 3 (0.75%) that would have diagenetic origin, being the rest (98.75%) of the samples, of thermogenic origin.

Lastly, based on considerations presented by Harworth et al. (1985), it is possible to estimate that the type of fluid, expected for this study area, would be predominantly liquid hydrocarbon, having a minor amount of condensed.

CONCLUSIONS

- The interpretation of the evaluated area in this study allows identification of 3 sectors with anomalous values of gasses.
- Generally, the samples taken north of block have a biogenic origin and the ones taken south of the area have a thermogenic character.
- Finally, taking into account the considerations presented by Harworth et al. (1985), it is possible to estimate that the type of fluid as expected from the area under study would be predominantly liquid hydrocarbon, with some minor quantity of condensate.

REFERENCES CITED IN THE ORIGINAL WORK

Duchscherer, W. Jr. (1984). Geochemical hydrocarbon prospecting, with case histories: Tulsa, PennWell Publishing Co., 196 p.

Haworth, J. H., Sellens, M. and Whittaker, A. (1985). Interpretation of Hidrocarbons Shows Using Light (C1 – C5) Hidrocarbons from Mud – Log Data, AAPG Bulletin, V.69, No.8, pp. 1305-1310.

Krumbein W. C. and Graybill, F. A. (1965). An Introduction to Statistical Models in Geology.

Isaaks, E. H. and Srivastava, R. M. (1989). An Introction to Applied Geostatistics.

Schumacher, D. and Abrams M. A. (1996). Hydrocarbons Migration and its Near-Surface Expression, AAPG Memoir 66.

Whiticar, M. J. (1994). Correlation of Natural Gases with their Sources, Chapter 16, en Magoon L. B. and Dow. G. W., The Petroleum System – From Source to Trap, The Petroleum System: Memoir 60.

PETROGRAPHIC AND PETROPHYSICAL ANALYSIS OF OUTCROP SAMPLES OF GEOLOGICAL CARTOGRAPHY PROJECTS, SINU-SAN JACINTO FOLDED BELTS[1]

C & CO SERVICES LTDA.

www.cycoservices.com

2007

GENERAL OUTLINES

The intention of present work is to integrate the petrograpical and petrophysical studies and analysis of samples and the geological, specifically sedimentological, information gathered in geological cartography projects, stratigraphical surveys and geological control in the seismic lines of the Sinu-San Jacinto Basin. The integration took effect for each reservoir formation of the Basin.

The rock samples of formations studied in this project mostly correspond to siliciclastic rocks. The evaluation of the reservoir quality in every single formation allows getting from low to high, prevailing *high quality of the reservoir* in the basin.

OBJECTIVE

To evaluate the reservoir quality of the basin by petrographic and petrophysical analysis.

[1] Análisis petrográficos y petrofísicos de muestras de afloramiento de los proyectos de cartografía geológica en: Grupo 2 Cinturón de Plegados de Sinú-San Jacinto. Informe Final. C&CO SERVICES LTDA. Agosto, 2007

METHODOLOGY

The following analyses and parameters for each reservoir formation were integrated and evaluated:

Petrographic: Depositional or detritus textures, diagenetical textures detritus composition or minerology, diagenetical composition or mineralogy, matrix types, cement types, porosity and pore types, porosity results (Petrograpical method or thin-section).

Petrophysical: Porosity, permeability, grain density, fluid saturation with retort.

Sedimentological: Lithofacies, lamination type or internal sedimentary structure, bioturbation and bioturbation intensity, stratigraphic column.

In order to classify the quality of the rock, the Winland correlation between porosity, permeability and the size of pore throat was applied, defining 5 categories to which different colours were assigned according to the following ranks:

Table 1. Criteria for the classification of samples by rock types

	Clasification	R35 Winland	Permeability
1	Very Goog	>8 µm	> 250 mD
2	Good	4 – 8 µm	50 – 250 mD
3	Regular	2 – 4 µm	10 – 50 mD
4	Bad	0.5 – 2 µm	1 – 10 mD
5	Very Bad	< 0.5 µm	< 1 mD

The Bioturbation levels mentioned in this report are according to the diagram shown in Figure 2.

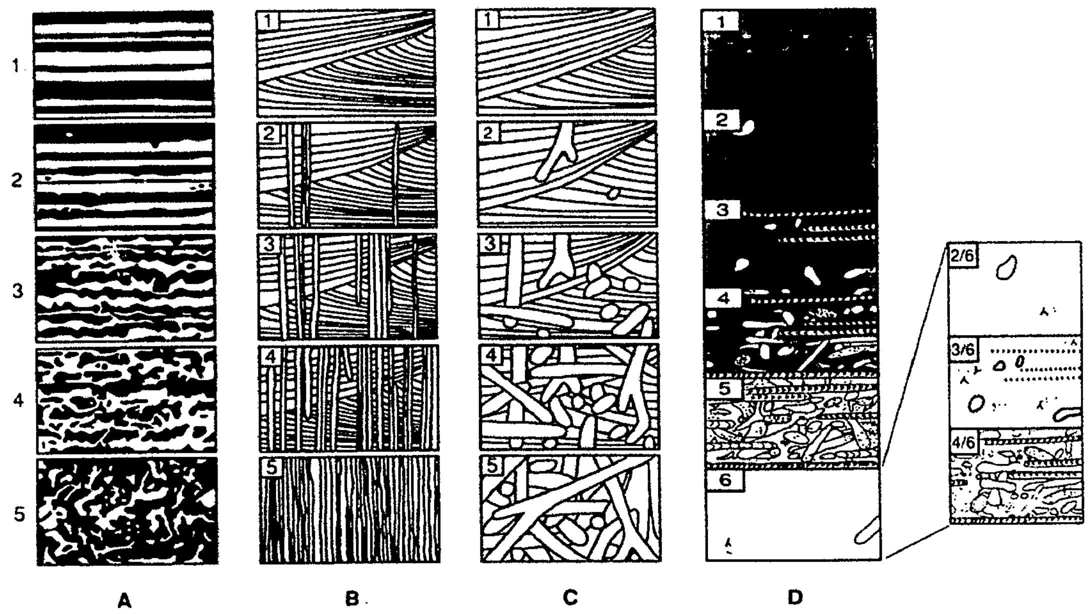


Figure 2. Schematic diagrames estimated from the bioturbation grade (ichnofrabric index). (A) Layers with thin lamination. (B) Layers with big thikness dominated by skoliths. (C) Layers with big thikness dominated by *Ophiomorpha*. (D) Deep water with fine grain environments.

Totally 90 samples were analized (Table 2).

Table 2. Analyzed samples from the Sinú-San Jacinto Basin.

FORMATION	ANALYSIS	
	PETROPHYSICS	PETROGRAPHY
Cansona	10	0
San Cayetano	11	6
Luruaco	29	18
Arroyo de Piedra	27	9
Pendales	3	0
Hibacharo	2	0
Tubará	1	0
Cerrito	2	0
Sincelejo	1	0
Rancho	1	3
Alférez (Rancho?)	3	3
TOTAL	90	36

RESULTS AND CONCLUSIONS

RESERVOIR QUALITY

The rock samples from the formations studied in this Project mostly correspond to siliciclastic rocks.The quality evaluation of reservoir in every single formation allows getting a variation from low to high prevailing moderate quality.

The Luruaco and Arroyo de Piedra formations feature the best aspects and the best data density; display from very low to high porosity measures (0.8-31.8%) and from very low to very high permeability (<0.002-192mD). The best samples are located in the Cerro Juan del Toro Area. Cansona and San Cayetano formations show a reduction of characteristics specialy very low values of permeability. The Pendales, Hibacharo and Sincelejo formations show very good features but low data density, which does not allow conclude about the reservoir quality (Figure 2).

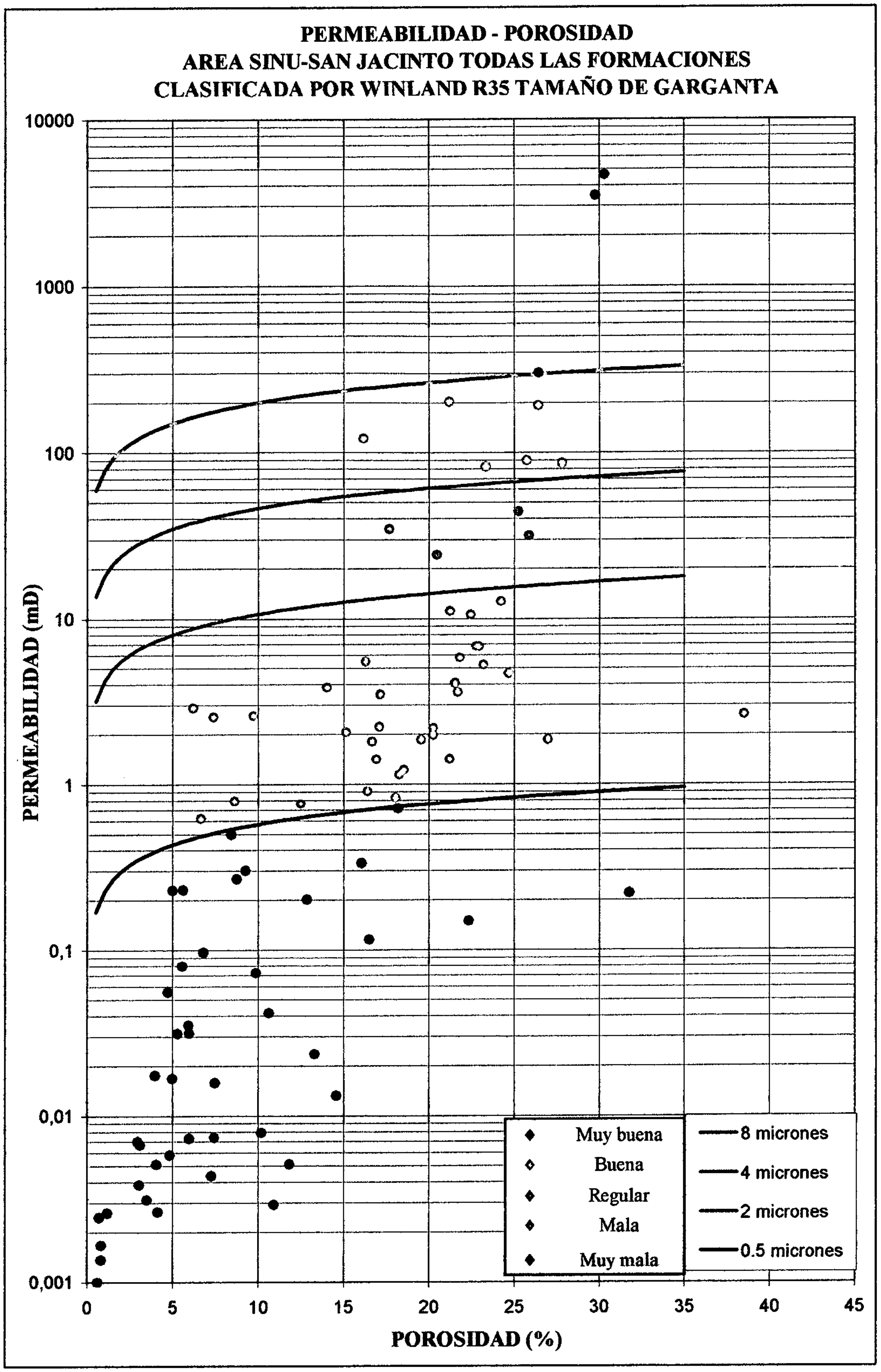


Figure 2. Porosity and Permeability of the rock samples from the Sinú-San Jacinto Basin.

The reservoir quality according to the formation are shown on the Table 3.

Table 3. Reservoir quality.

FORMATION	RESERVOIR QUALITY
Cansona	Moderada
San Cayetano	Variable (Baja – Alta)
Luruaco	Variable (Moderada– Alta)
Arroyo de Piedra	Variable (Baja – Muy alta)
Pendales	Excelente
Hibacharo	Excelente
Tubará	Baja
Cerrito	Regular
Sincelejo	Excelente
Rancho	Baja

REFERENCES CITED IN THE ORIGINAL WORK

Folk, R. L., 1974, Petrology of sedimentary rocks: Austin, texas, hemphill's Book Store, 170 p.

Unión Temporal B&G. Cartografía Geológica de los Cinturones Plegados Sinú – San Jacinto,Geostudios Ltda., 2006. Cartografía Geológica Cuenca Cesar – Ranchería.

SINU SAN JACINTO 2D 2005[1]

SISMOPETROL S.A.
www.sismopetrol.com

PGS
www.pgs.com

ALBORADA PROVISIONAL JOINT VENTURE

2006

INTRODUCTION

The Sinú-San Jacinto 2D 2005 Seismic Program was located north of the country, in the Colombian Caribbean Basin (in Córdoba, Sucre, Bolívar, Atlántico and Magdalena departments), and was carried out during December 2006.

The Project consisted on 10 regional lines: 6 in E-W direction and 4 in N-S direction, which started on the coastal zone of the Caribbean Sea (Figure 1) and included 886.0 km of topographic survey, 16130 drilling wells plus 800 additional wells, and 16930 wells records.

[1] Sinú-San Jacinto 2D 2005. Informe Final. Unión temporal Alborada. Diciembre, 2006.

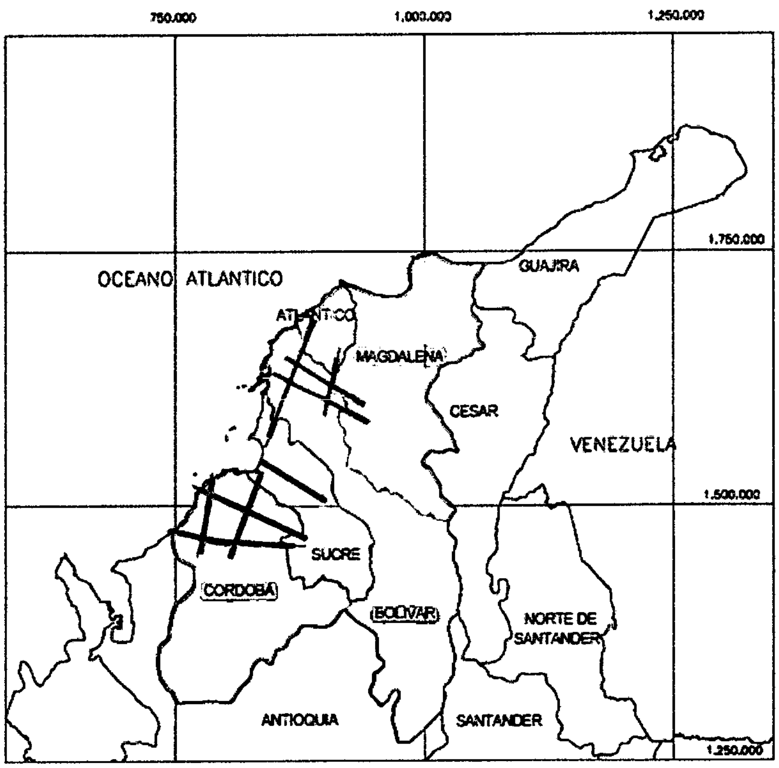


Figure 1. Study area location.

Methodology and Resluts

The seismic data acquisition consisted of 10 lines with receptor stations located every 25 m, with shot points every 50 m. By using a GPS system a three-point base was set up in order to adequately configure conventional topography equipment. The temperature, atmospheric pressure, height, and the proportion of parts per million (ppm) were reconfigured, in order to obtain actual on-site land distances. Landmarks for 27 GPS network corners were set, each one with its mark and its respective azimuth sign.

For the seismic program 900 g and 1800 g units of sismigel were used as energy sources. For the borehole charging, Peruvian FAMESA's electric detonators specific for the seismic surveys were used.

Data acquisition was performed by means of two devices: Sercel CM408XL in the North Block and CM408UL in the South Block. The following is the processing sequence carried out on the lines:

1. SEG-D Conversion to ProMAX.Format
2. Setting and loading of Geometry
3. Trace editing
4. Tue amplitudes rcovery
Type: 1/dist Spherical divergence
5. Trace equalization
6. Trace-by-trace deconvolution – minimum predictive phase
Operator length: 160
Operator prediction distance: 24
White noise percentage: 0.1%.
7. Application of statistics by elevation:
Datum 300 m
Velocity 2000 m/s
8. Velocity analysis every 1000 m
9. CDP stacking
10. Band-pass filter. Frequencies: 8 - 12 – 45 – 65
11. Automatic gain control: 500 ms
12. Stack with refraction statics
13. Stack with residual statics
14. FK 100% migration

The area of influence of the project is located in the Córdoba, Sucre, Bolívar, Atlántico, and Magdalena departments. In this area we found the following elements: Quaternary Alluvial deposits (Qlai) and tertiary deposits mainly in the Floresanto Unit (Ngf), Morrocoy El Pantano Unit (Ngmp), Moñitos Unit (Ngmn), Broqueles Unit, Pajuil Loma Verde Unit (Ngpas) and Pajuil Cerro Verdinal Unit (Ngpai), San Cayetano Formation (Pgsc), Cerrito Formation (Ngc), El Floral Formation (Pgf), Sincelejo Formation (NgQs), Betulia Formation (Qpb), Boquetes Unit (Ngb), El Carmen Formation (PgNgc).

Signal reception is good all along the entire project, and environmental noise was adequately controlled. Figure 2 depicts an example of the obtained records:

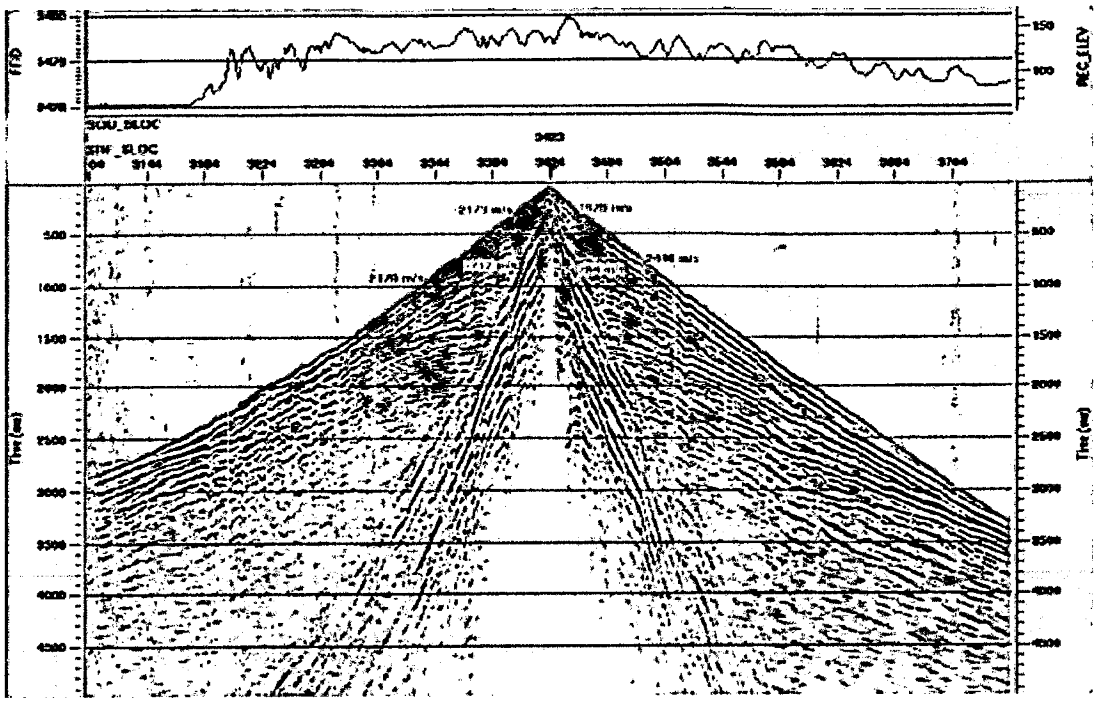


Figure 2. Speed of first arrivals and groundroll

Levels of Energy and Dominant Frequencies

The level of energy is directly related to geology, tectonics, relief, environmental noise, lithological formations, depth, and amount of used charge. In general, the energy levels throughout the project were good. The values of reflector frequencies are between 10 and 20 Hz, and for ground roll between 5 and 10 Hz.

Signal/Noise analysis

Many sources of noise were evidenced, namely: Montería-Sincelejo road, Barranquilla-Cartagena road, Montería-Cereté road, Sincelejo-Tolú road, Corozal-Sincé road; towns on the route of the various lines, as well as swamps, small lakes, cement industries, sea ports, among other factors.

Figure 3 depicts examples of a non-processed record and a record to which a band-pass and AGC filters were applied, to show how information is retrieved and noise treated by applied filters.

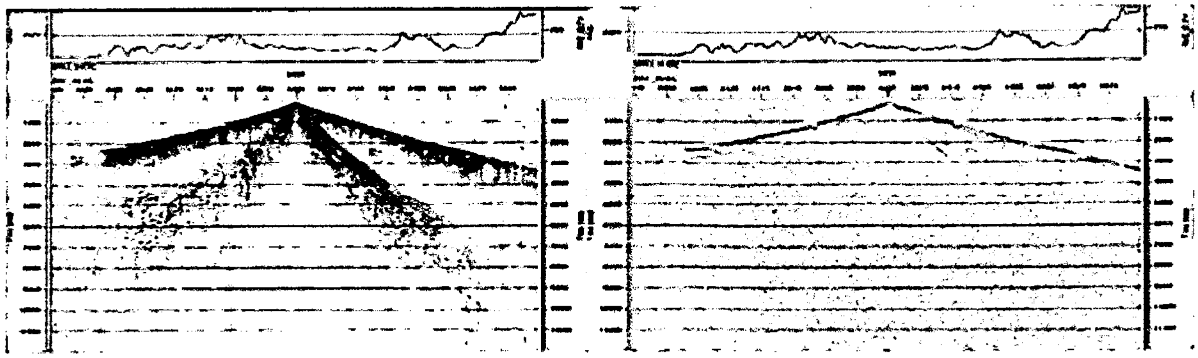


Figure 3. Unfiltered record and filtered record: Bandpass 8-12-45-65, AGC 500 ms.

Final Process

After revising the geometry, and once the SPS consistency is guaranteed, the process sequence previously established is applied. After obtaining the data provided by the deconvolution, the velocity analysis is carried out corrected for a range of 80 cdp's equivalent to 1000 m and a velocity range between 1400-7000 m/s. Furthermore, CDP stacking is performed, with elevation and refraction statics. In addition, a FK migration (100%) was carried out. Figure 4 shows an example of the FK migration at 100% up to 6 seconds.

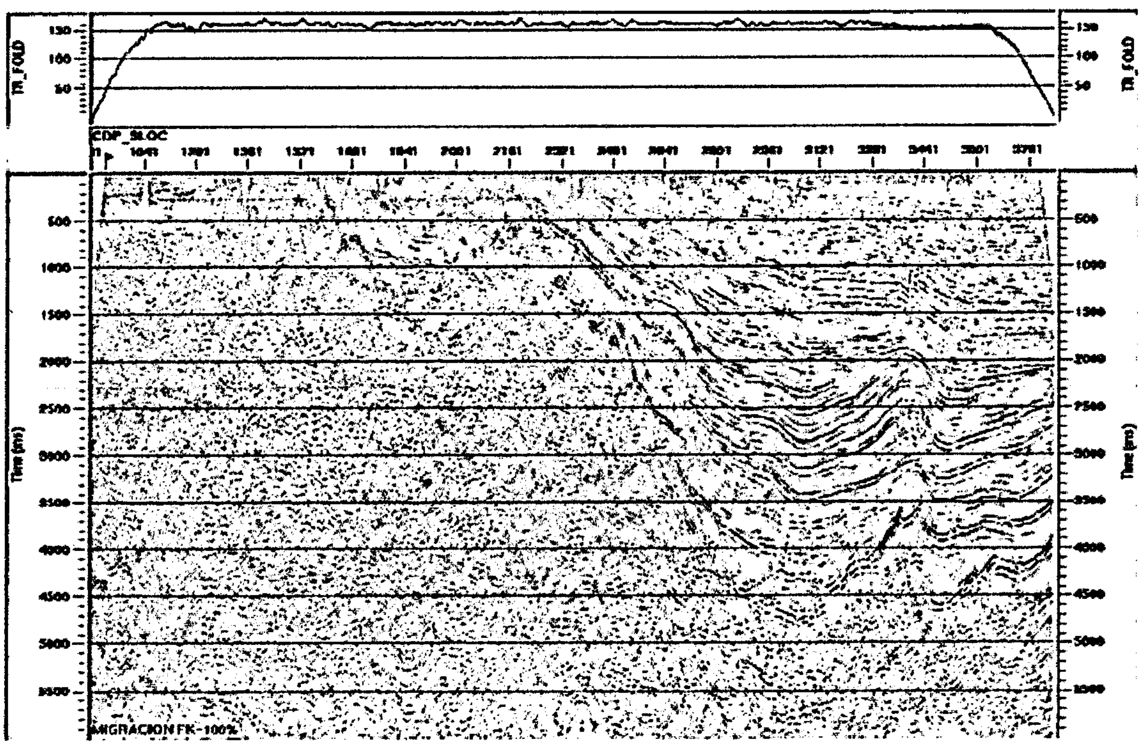


Figure 4. FK migration at 100% up to 6 seconds.

CONCLUSIONS AND RECOMENDTIONS

The quality of the records for different lines was generally good, except for lines like ANH-SS-2005-05 and ANH-SS-2005-01, where it was deficient. All project lines presented statics on a constant basis, which affected while-record performance throughout the lines. Most of the lines showed bad records for far offsets, and this prevented, in some cases, a clear vision of events in the area. Reflector continuity, in general, is up to 6 and, in some cases, 8 seconds.

REFERENCES CITED IN THE ORIGINAL WORK

INVENTORY, INTERPRETATION AND INTEGRAL EVALUATION OF GEOLOGICAL, GEOPHYSICAL AND GEOCHEMICAL INFORMATION OF BOTH SINU- SAN JACINTO BASIN AND SINU SPECIAL AREA[1]

UNIVERSIDAD DE CALDAS

www.ucaldas.edu.co

2008

OBJECTIVE

To perform an inventory of available information about the basin, assessing the quality of this information, and making an integral interpretation and evaluation of geological, geophysical and geochemical information acquired by Agencia Nacional de Hidrocarburos (ANH) in both Sinu-San Jacinto Basin and Sinu Special Area.

OVERVIEW AND BACKGROUND

Geographical location

The study area is located in the Caribbean Region, northeast of Colombia, on the western side of the Lower Magdalena River Valley, and embraces the northern sectors of Antioquia, Cordoba, Sucre, Bolívar, and Atlantico departments between coordinates 76°40'12" and 74°30'14.4" W and 7°20"9,6" and 11°6'46.8' N (Figure 1).

[1] Inventario, interpretación y evaluación integral de la información geológica, geofísica y geoquímica en la Cuenca Sinú-San Jacinto y el Área Especial Sinú. Universidad de Caldas. 2008.

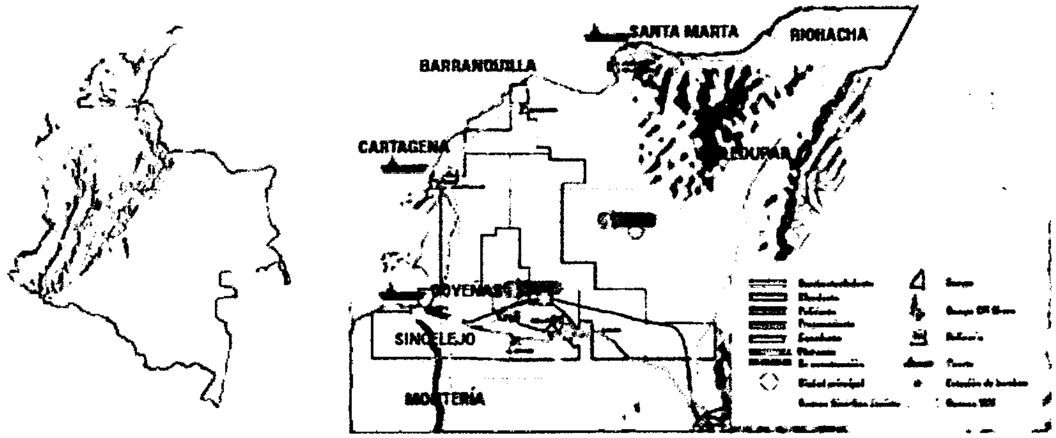


Figure 1. Location map of the study area.

Regional Geological Frame

Study area is located in a zone, where its geological evolution has been closely associated with tectonic events, resulting from interaction between the South American Plate (Andean Block), Caribbean Plate, Nazca Plate, and Choco Block. From late in the Cretaceous, this plate interaction has led the Caribbean plate to relatively migrating towards the east along the north of South America, showing an incipient state of ocean-continent subduction evidenced from the existence of a slight continental acreation, and deformation prism, where no calco-alkaline volcanism has been developed, and there is no typical seismic condition associated with subduction (Taboada et al., 1998). Areas involved in the evolutionary history of the area were deposited in the margin of two well differentiated provinces, separated by the Romeral Paleosuture. These geological provinces have a continental basement in the east (Lower Magdalena Valley Basin) and oceanic basement in the west (Sinu Basin and San Jacinto Folded Belt).

Greater tectonic elements

Tectonic evolution of the Colombian Caribbean has led to formation of several geological provinces, which can be studied from respective structural and stratigraphic particularities (Duque-Caro, 1980). In the work area, these provinces are represented by the Lower Magdalena Valley Basin, San Jacinto Folded Belt and Sinu Basin (Figure 2). The most important structures involved in the tectono-stratigraphical evolution of the Colombian Caribbean are the Romeral Paleosuture, Sinu Fault, Magangue or Cicuco Arch, Santa Marta-Bucaramanga Fault, Oca Fault, and Uramita Fault, which, as a whole, have determined the history of the geological area, defining not only the structural style of the different geological provinces, but also the evolution of the deposit bottoms and facies accumulated over the evolutionary history of the Colombian northern region.

Figure 2. Distribution of the main structural elements of tectonic provinces on a Radarsat image of the Colombian northeast.

Straigraphy, Regional Correlations, and Sedimentation Environments

Table 1 includes a description of area units, ages, composition, litho-stratigraphic and alo-stratigraphic units, sedimentary environments, and tectonic frame.

Table 1. Description of litho-stratigraphic and alo-stratigraphic units in the area.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]

Cartography-Structural Geography

This geologic map is made up of field and photo-geologic information developed in the area, in addition to a new interpretation of remote sensors with a modern approach, according to the alo-stratigraphic frame, in order to reflect the evolution of the different basins involved in the work area. Special care has been taken using the greatest quantity of surface information of available maps, which has been integrally filtered and evaluated with the interpretation of satellite information, and stratigraphic and seismic 2D evaluation of wells. Integration, evaluation and generation of the final geological map were based (in addition to the interpretation of remote sensors) on data analysis from diverse maps produced by different companies, and obtained in different forms (Figure 3).

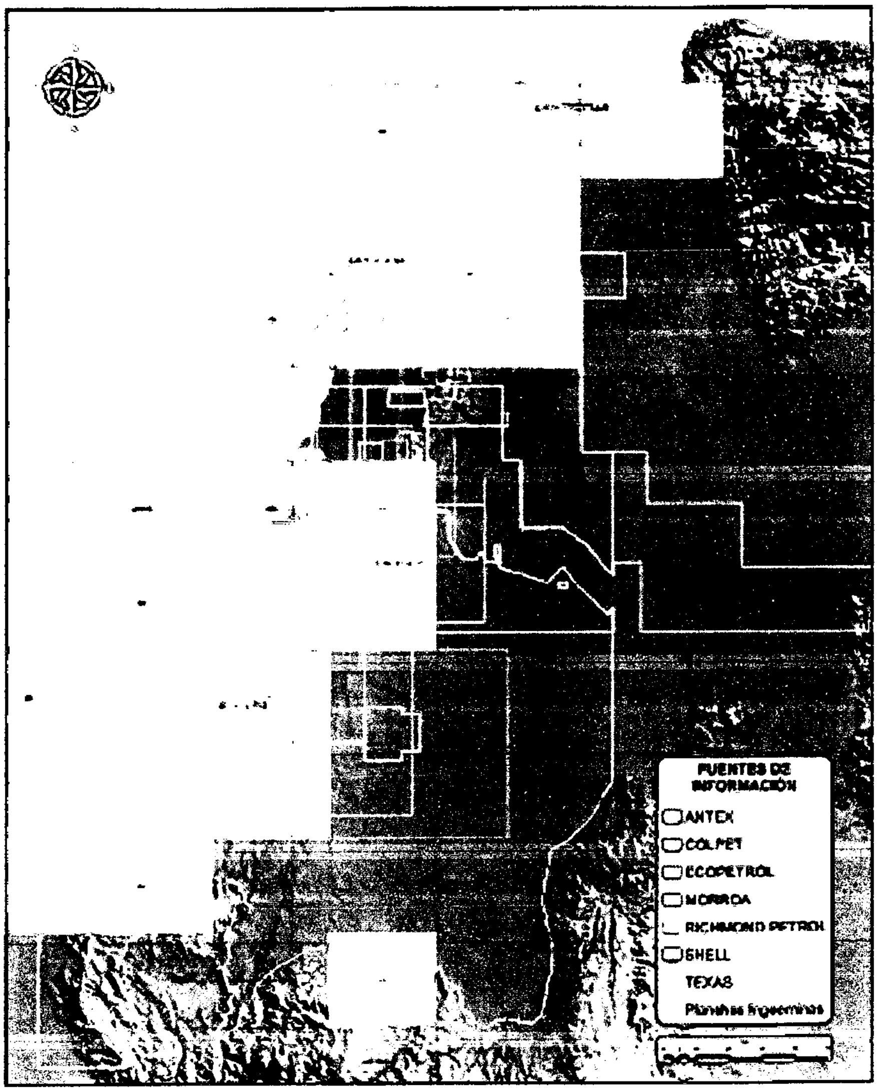


Figure 3. Information sources for the integrated geological map.

Work area involves three well differentiated geological provinces, to wit: the Lower Magdalena Valley, San Jacinto Folded Belt, and Sinu Folded Belt. Figure 4 shows the location of Lower Magdalena Valley and its geological provinces.

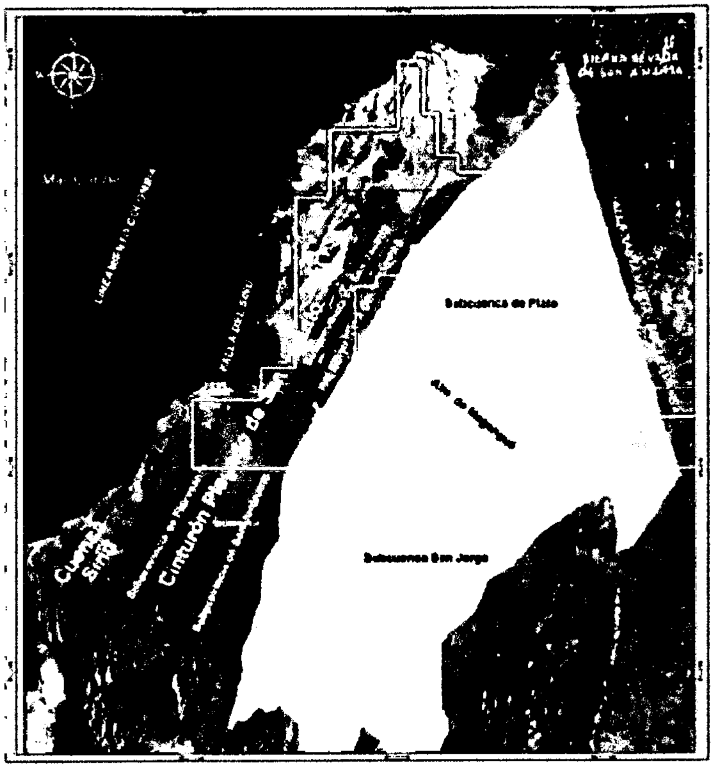


Figure 4. Location of Lower Magdalena Valley and its geological provinces. Map obtained under interpretation of a Radarsat Image.

Seismic Interpretation

The main purpose of this work is the identification of regional stratigraphic horizons allowing to divide the sedimentary coverage in alo-stratigraphic units in the Lower Magdalena Valley and San Jacinto Folded Belt, and learning the space-time distribution of these horizons reflected in time-depth structural maps.

The information used in this work includes well records and construction of synthetic seismographs, well files with check shot, well images where composed graphic records and electric records were included, technical reports, which included: well records and technical reports on interpreted seismic lines.

Loaded seismic information covers the Sinu-San Jacinto Basin and Lower Magdalena Valley for the area designated for this project, which embraces 4133.3 km represented by 138 lines (Figure 5). From the 138 mounted lines, 54.35% are seismic lines of good quality, 33.33% of fair quality and 12.32% of bad quality.

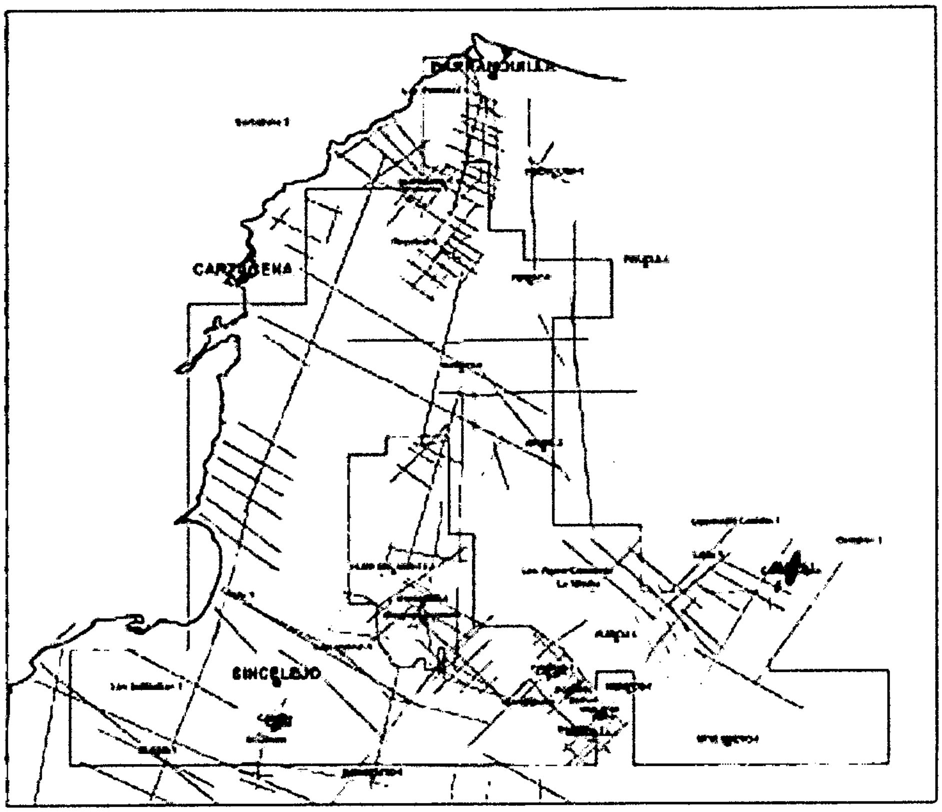


Figure 5. Map of distribution of seismic lines and partial wells.

Based on available literature and the interpretation of seismic lines, along with biostratigraphic interpretation of wells, the following regional horizons were defined: Limit of Crystalline Basement, Limit of Maco, Maralú, San Jacinto, and Porquera alo-formations, and the bases of El Cerrito and Lower Sincelejo Alo-formations. Interpretation was made of western zones of Romeral Faults belonging to Plato Basin and Alto Cicuco or Magangué, located in an environment associated with transcurrent movement of Romeral and Santa Marta-Bucaramanga faults. Areas with a somewhat homogeneous distribution of seismic grid, allowed the obtention of time-depth structural maps , and isopachous for two zones in particular.

Gravimetric and Magnetometric Correlation vs. Structural Map of Basement in Depth

By correlating the depth map generated for the basement with Bouguer anomalies, Residual, and Magnetic Anomalies maps prepared by Carson Services (2005) (Figure 6), a close relationship was found between the most positive gravimetric and magnetometric anomalies, which reflect the basement position. It also happens with the most negative gravimetric and magnetometric anomalies especially located near the Plato and San Jorge basins and the greatest values of depth in the basements maps, which reflect the presence of greater thicknesses of sediments where the basement reaches some depth. It is worth noticing how the time-depth decrease in high Cicuco and Magangué, and in the Romeral Fault, which is a sector showing a series of positive magnetic anomalies.

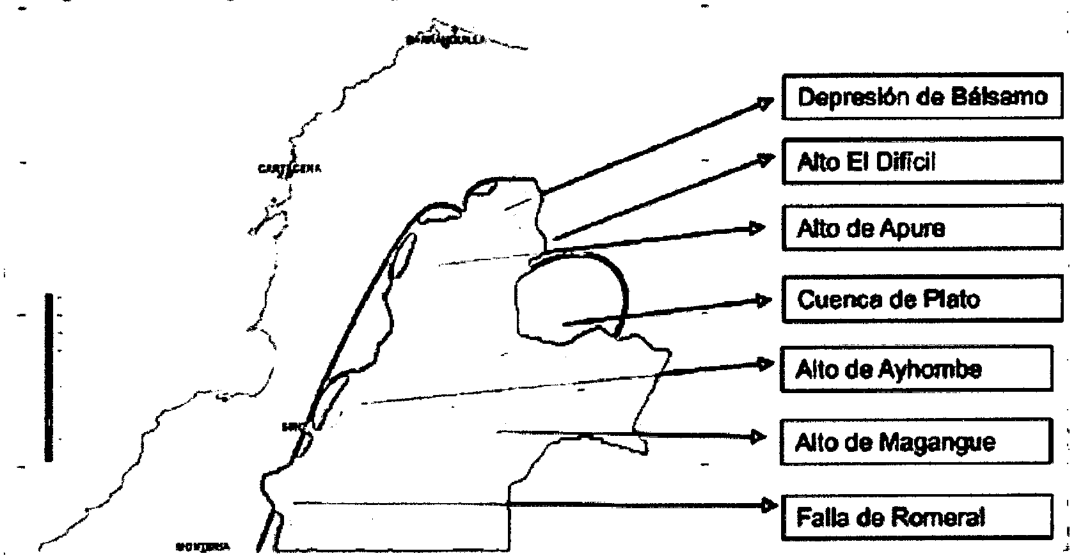


Figure 6. Structural Map of the Basement with the major geological features for the Lower Magdalena Valley Basin.

Processing

The objective of this re-processing work is reviewing the generation of pre-stacking data migrated in time for which purpose some different groups of 2D seismic data were obtained through a consistent processing system, which allowed a better visualization of the structures. The 2D Seismic information is divided into three groups (data and recording parameters), as listed below: SAN JACINTO 2D-2005, NW-COLOMBIA-84, SANTERO-95.

Initial tests and applied processing sequence allowed an adequate treatment of effects close to the surface due to some variations in the elevation and to meteorized layers. They also allowed the generation of final migrations to a standardized datum of 300 m. Seisup software was used for seismic processing, using the Kirhchhoff algorithm to perform the pre-stack up migration in time. Among this processing routines are the following: Amplitude recovery, F-K Filter, Refraction Statics Tests, Deconvolution, Binning, F-K Deconvolution, Velocities Analysis, Multiplies elimintaion, Migration Parameters Tests, Filters and final Gain. Figure 7 shows results of sections PSTM with their respective velocity fields (Figure 8) for line ANH.SS-02, generated from the proposed processing sequence.

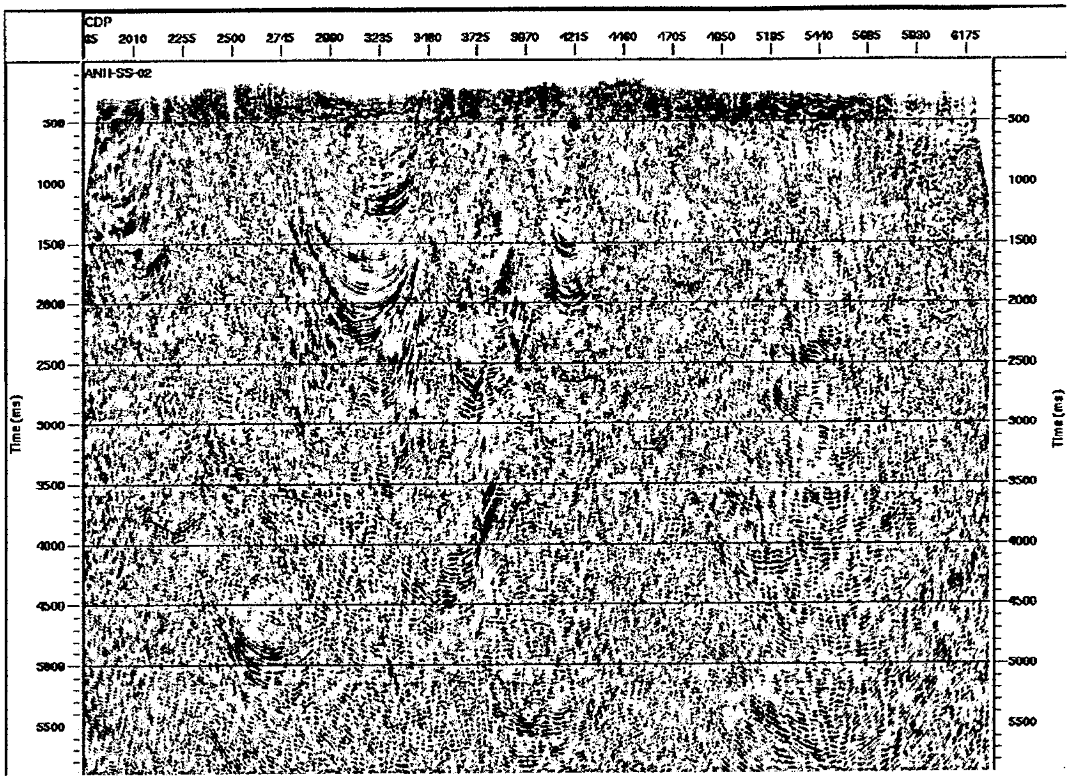


Figura 7. PSTM - línea ANH-SS-02.

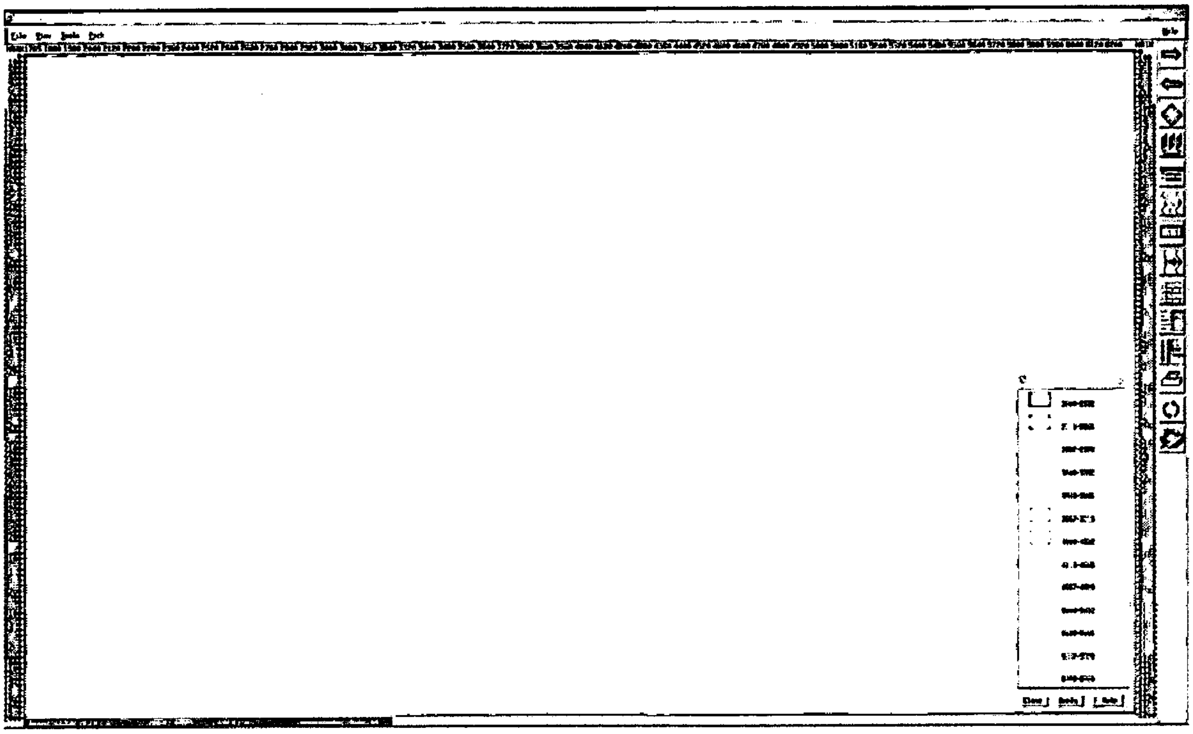


Figure 8. PSTM velocities field – Line ANH-SS-02.

PETROPHYSICAL EVALUATION

This evaluation involves review of 34 out of 65 wells existing in the study area. Three interpretation models were prepared according to the curves available for the interpretation. The first model includes spontaneous potential curves,Gamma Rays, low, medium and deep resistivities, bulk density, neutron and acoustic porosities. The second model includes above-mentioned curves, and omits the density and neutron curves. The third model only includes the curves of spontaneous potential,Gamma Rays, resistivity curves and acoustic records. The main objective was detailing the effective porosity at the level of horizons known to be productive in the study zone.

Based on well information zones of interest were located for Ciénaga de Oro, Maco, and San Jacinto horizons with approximate thickness of 75 feet, in accordance with their saturation potential and/or Netpay conditions. The effective porosity was mmaped, which generated the grid that allowed the evaluation of the average porosity for each of the horizons.

Table 2. Effective porosity ranges for the different formations deemed producers.

Formation	Effective porosity		
	Minimal	**Maximal**	**Average**
Ciénaga de Oro	2.63%	2.81%	12.69%
San Jacinto	0%	44.90%	11.34%
Maco	0%	29.00%	9.25%

Based on information contained in the templates of each well (see example in Figure 9), the values of petrophysical properties of each well were obtained.

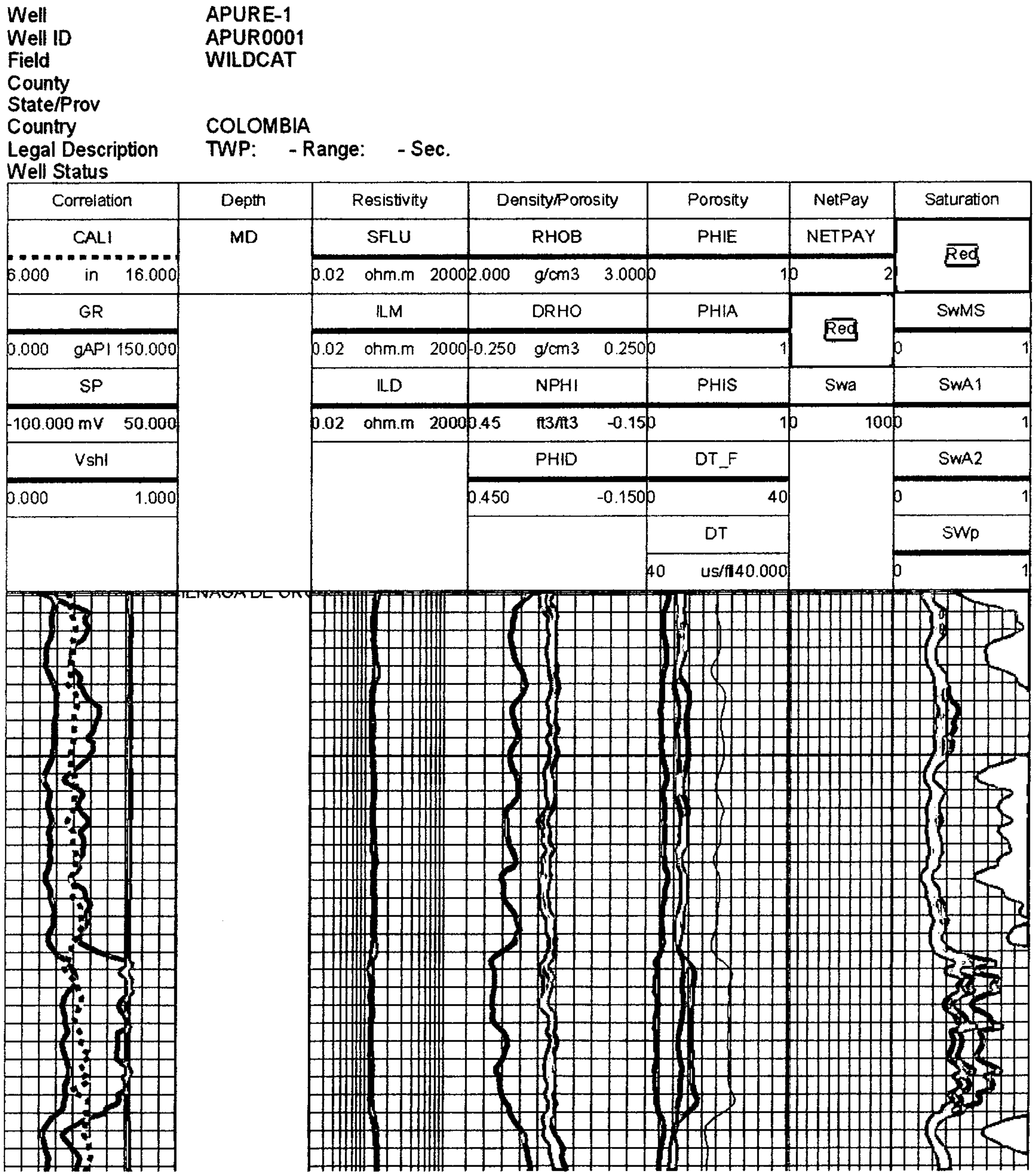


Figure 9. Template .1 for interpretation of wells (GR, SP, Vshl, Rs, Rm, Rd, RHOB, NPHI, DT, PHID, PHIS, PHIA, PHIE Swa, SwA 1m SwA 2, SwMSm Netpay).

Regional Geochemical Evaluation

In order to determine the evolution, quality and maturity of generating rocks, as well as the origin of crude oils in the Sinu-San Jorge Block, some information was gathered. It includes data on pyrolysis Rock-Eval and TOC of ditch and well samples, liquid and gas chromatography, biomarkers, and data on carbon isotopes of aromatic and saturated fractions of crude oils and rocks extracts.

Source rock maturity

Although most of the samples are immature (Tmax <435° C) it is noticed that from 9000 feet on, the quantity of samples entering the hydrocarbon generating window (Tmax > 435° C) start increasing, and that among units entering this window are the Cerrito, Porquera, and Ciénaga de Oro formations.

Source rock quality

Hydrogen index values are low, below 200, this means the presence of kerogen type III, which involves a gas-generating and, as a consequence, poor quality for generation liquid hydrocarbons. However, considering the existence of oils traces on the surface and in some wells, it is clear that there would be facies at the local level generating liquid hydrocarbons of good quality according to API well gravity data, although in a smaller proportion than gas.

Organic matter contents (TOC)

In general, samples show values ranging between regular and poor condition (<2%) with some samples showing good quality values (> 3%) from Ciénaga de Oro formation.

RESULTS AND CONCLUSIONS

Lower Magdalena Valley Basin

Kerogen type and hydrocarbon accumulations

In this basin the geochemical data suggest the presence of humus-soil organic matter (kerogen type III) for all the sequence settled therein, a condition indicating mainly gas-producing situation. However, the presence of liquid hydrocarbons in a smaller proportion than gas, suggests the existence of levels with oil-producing organic facies, although probably aerially restricted, and of little thickness. This is inferred from the few samples where the organic matter contents (TOC) and the hydrogen rate are high enough to produce liquid hydrocarbons.

Source rock thermal maturity

Maturity data and geochemical models indicate that rocks enter the oil generating window with 10000-11000 ft depth. No evidence is available on organic matter over-maturity in the accessible information. However, the existence of high gravity crude oils (API > 30°) and some biomarker data suggest that source rocks may have reached high thermal maturity in some basin areas, and the geochemical models indicate that maturity condition could be achieved at approximately 15000 feet of depth.

Oil Reservoir Systems

Oil reservoir rocks represent a thick sequence of sandstones, whose origin is fluvial/deltaic on the Ciénaga de Oro Formation. They are intercalated with fine grain rocks (shales) of fluvial/marine origin, which act as source rocks, according to chemical available data, and local seal. Regionally, petrophysical data on Ciénaga de Oro Formation indicate that porosity values vary between very low (around 3%) and very high (about 30%) with a 13% average value.

Figure 10. Zones of prospecting interest in the Sinu Norte area San Jacinto folded belt Kerogen type and hydrocarbon accumulations

San Jacinto Folded Belt

Kerogen type and hydrocarbon accumulations

As it occurs in the Lower Magdalena Valley Basin, geochemical data suggest the presence of organic matter of humus-soil origin of kerogen type III for all the settled and deposited sequence, which mainly produces gas. However, the presence of liquid hydrocarbons, although in a smaller proportion than gas, can not be discarded due to the multiple oil seeps reported in the basin (Figure 10).

Generating rocks thermal maturity

Maturity data suggest that Oligocene and older ones rocks have reached conditions of oil generating windows in most of the folded belt, and they show a trend to an increased maturity towards the west (Figure 11). There is no evidence of organic matter over-maturity in available data.

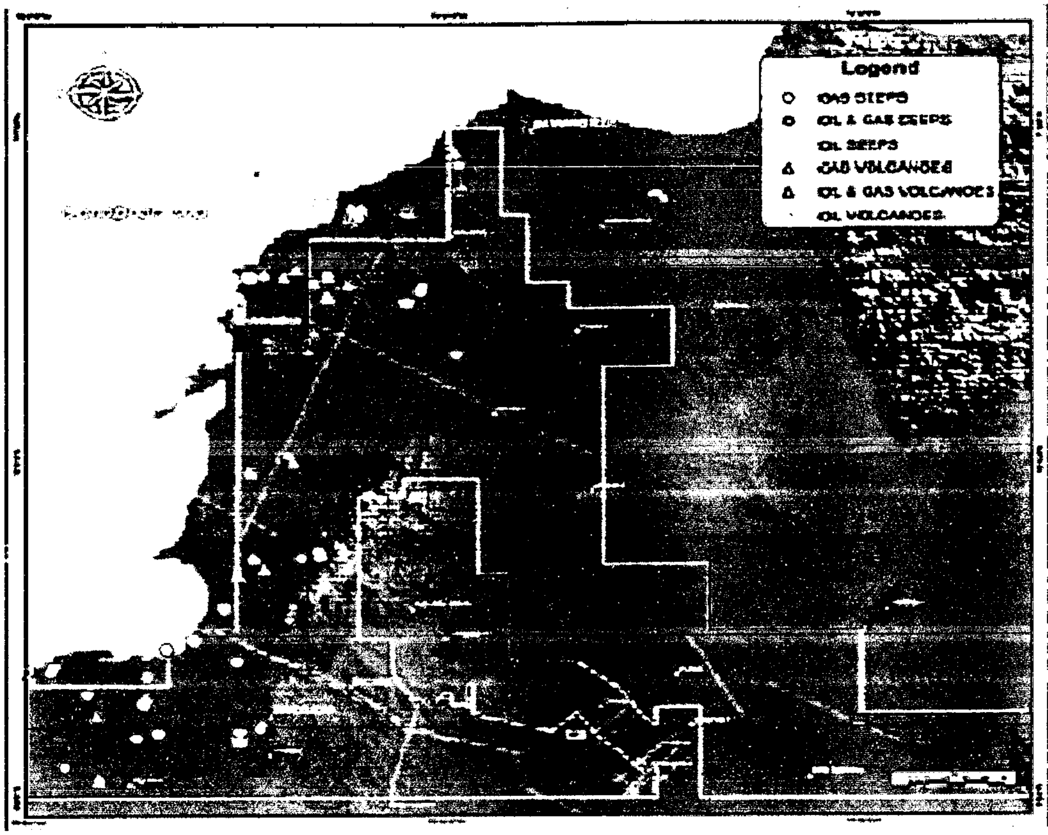


Figure 10. Map of seeps and mud volcanoes in San Jacinto Folded Belt.

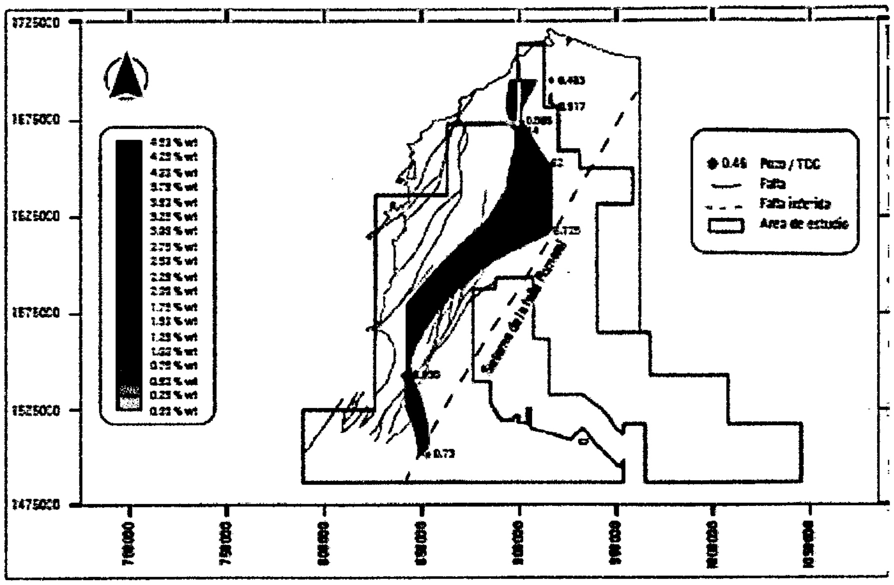


Figure 11. Map of distribution of Tmax of Maralu Formation samples.

Figure 12 shows the distribution of areas of interest identified in the Lower Magdalena Valley Basin and in San Jacinto Folded Belt. Orange colored areas are the zones where it is possible to observe folding, onlap and/or structural truncation by normal faults of sediments of Ciénaga de Oro Formation against the basement. Blue colored areas are those where morphologies of valley incision are observed. Yellow colored areas are those where anticlinal folds are observed, which involve the Maco and San Jacinto formations. Pink colored areas are those where folds and channel morphologies are observed, which involve Maco, San Jacinto, and San Cayetano formations. Finally, light blue colored areas, and in the southwestern end of Sinu Norte Special Area, are observed diapyric structures affecting the sedimentary sequence, and create folds and truncations susceptible of storing hydrocarbons.

Figure 12. Zones of prospecting interest in Sinu Norte area.

REFERENCES CITED IN THE ORIGINAL WORK

Caro, M., Spratt, D. (2003). Tectonic evolution of the San Jacinto fold belt, NW Colombia. FRP research report – volume 8, 23 p.

CARSON SERVICES (2005). Programa "Adquisicion Procesamiento e interpretación de datos de Aeromagnetogravimetria en el Litoral Caribe, Cuencas de Sinú, San Jacinto, Plato y San Jorge Inc. Aerogravity Division.

Duque-Caro, H. (1980). Geotectónica y evolución de la region noroccidental Colombiana. Boletin Geológico INGEOMINAS, v. 23, No 3, pp. 4-37. Bogotá, Colombia.

Kellogg, J. N. and Vega, V. (1995). Tectonic development of Panama, Costa Rica and Colombia Andes: Constrains from Global Positioning System geodetic studies and gravity. In: Mann, P., (ed) Geologic and Tectonic Development of the Caribbean Plate Boundary in South Central America. Geological Society of America. Special Paper 295, pp. 75-90.

Kerr, A. and Tarney, J. (2004). Tectonic Evolution of the Caribbean and Northwestern South America: the Case for Accretion of two Late Cretaceous Oceanic Plateaus.

Disponible en: http://www.earth.cf.ac.uk/ people/summaries/ACK.Geology-2005.pdf. Página consultada el 20 de Septiembre de 2007.

Meissner, R.O.; Flueh, E.R.; Stibane, F. and Berg, E. (1976). Dynamics of the active plate boundary in southwest Colombia according to recent geophysical measurements. Tectonophysics, 35, pp. 115-136.

Moldowan, J.M.; Seifert, W.K. and Gallegos, E.J. (1985). Relationship between petroleum composition and depositional environment of petroleum source rocks. AAPG Bulletin, Vol. 69, pp. 1255-1268.

Moreno, O. Suarez, M. & Acevedo, H. (2006). ECOPETROL S.A. Adquisición Sísmica Regional Compuesta Terrestre-Transición-Marina en el Caribe Colombiano. Memorias IX simposio Bolivariano Exploración Petrolera en las Cuencas Subandinas. Cartagena de indias.

Peters, K. E. & Moldowan, J. M. (1993). The Biomarker Guide. Interpreting Molecular Fossils in Petroleum and Ancient Sediments. Prentice Hall, Englewood Cliffs, N.J.

Taboada, A.; Dimaté, C. and Fuenzalida, A. (1998). Sismotectónica de Colombia: deformación continental activa y subducción. Física de la Tierra, No 10, pp. 111-147, Bogotá.

Trenkamp, R., Kellog, J. N., Freymueller, J. T. Nad Mora, H. P., (2002). Wide plate margin deformation, southern Central America and northwestern South America, CASA GPS observations. Journal of South American Earth Sciences, v. 25, 2, pp. 157-171.

7. REGIONAL STUDIES

AIRBORNE GRAVITY AND MAGNETIC SURVEY PROGRAM: ACQUISITION, PROCESSING AND INTERPRETATION OF GRAVITY AND MAGNETIC DATA ON THE PACIFIC LITTORAL OF COLOMBIA[1]

Carson Helicopters, Inc./Aerogravity Division

www.carsonhelicopters.com

2006

SUMMARY

Carson Aerogravity a Division of Carson Helicopters, Inc. conducted for the Agencia Nacional de Hidrocarburos (ANH), an airborne gravity and magnetic survey of Pacific Littoral, Colombia. Data from the airborne system are processed for acceleration, speed changes and departures from the flight reference surface made along each individual survey line. A profile is made for each survey line from the following parameters: topography, spring tension in milligals, Eötvös, GPS elevation, GPS PDOP, vertical accelerations calculated from the GPS data, average beam times "K" (i.e., "K" being a constant). and three plots of the free-air gravity with various levels of filtering. This report is intended to present the gravimetric and magnetic data processing and interpretation of the Pacific Coastline of Colombia, from the boundaries with the Republic of Ecuador to the Gulf of Uraba and the Republic of Panama. The entire zone occupied by the gravity and magnetic survey performed by Carson in 2006, as well as the 2000 year progamm in Buenaventura is delimited to the east by the Eastern Cordillera and to the west by the Pacific Ocean.

---

[1] Programa adquisición, procesamiento e interpretación de dtos de aeromagnetogravimetría en el Litoral Pacífico de Colombia. Informe sobre Procesamiento de Datos e Informe Final de Interpretación. Noviembre, 2006.

The interpretation was focused on the definition of the top of Cretaceous basement, in an effort to define both the location of areas where the biggest thickness of Tertiary sequences may occur, including structural heights where hydrocarbons could be trapped in the sandy facies and in fractured calcareous formations in San Juan Group and its structural wedging, while the basement becomes scarce towards the foothill of the Western Cordillera and the border of the Pacific Platform.

OBJECTIVE

Perform the gravity and magnetic data acquisiton, processing and interpretation on the Pacific Littoral of Colombia. The interpretation was focused on the detection of exploratory objectives associated to Tertiary sedimentary deposits, which could result in a generation, and trapping of hydrocarbons.

GENERAL

Survey Area Description

In 2006 Carson Helicopters Inc (Aerogravity Division) carried out the acquisition and processing of an airborne gravity and magnetic survey on the Southern Pacific Littoral for the National Hydrocarbons Agency (ANH). A DeHavilland twin outer turbo plane performed the acquisition of about 19499 km of gravity and magnetic data respectively, on a 7.5 km x 10 km flight path. Geophysical data were acquired at an average height of 1280 m above the sea level.

Figure 1 depicts the interpretation zone location, including the existing topographical relief. The Colombian Pacific Littoral Basin is located between latitudes from 01°30'N to 08° 30'N and longitude from 76°30'W to 79°10'W.

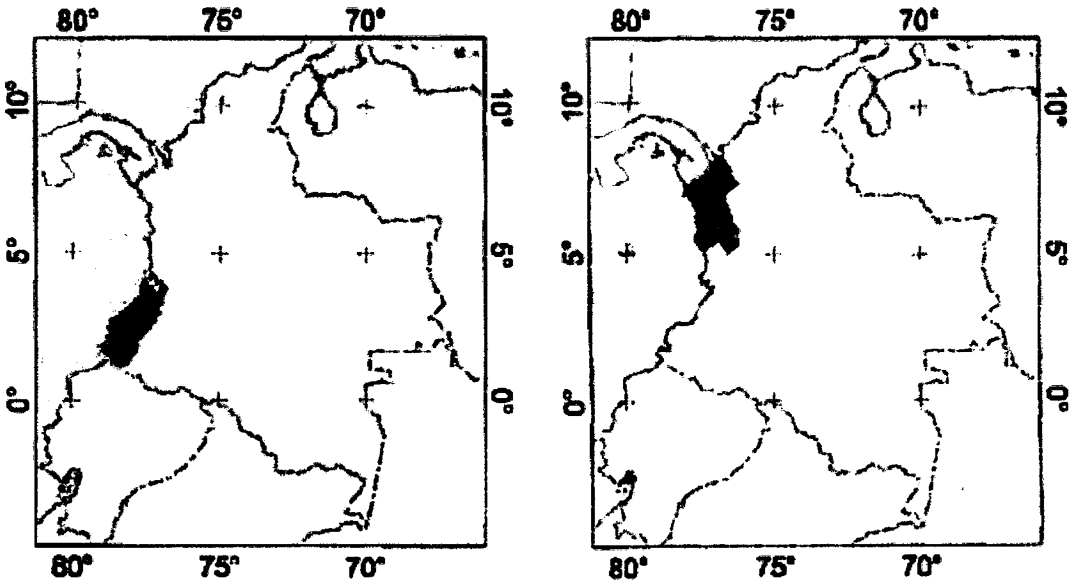


Figure 1. Survey Location Diagram. (a) – South Part; (b) – North Part.

DATA ACQUISITION

Survey System

The airborne gravity and magnetic survey system, outlined below, was developed and patented by Franklin D. Carson and William R. Gumert in 1984 after years of extensive research and field testing. The Caribbean Littoral, Colombia survey was performed using a DeHavilland Twin Otter, N920R, and a DeHavilland Twin Otter, N239Z fixed wing aircraft.

Navigation

Aircraft navigation is maintained through the use of the NAVSTAR Global Positioning System, (GPS), and a real time navigation system. Satellite signals are received by a single antenna contained in the RF unit mounted on top of the aircraft where it receives the maximum signal strength with minimum interface. The antenna is right-hand circularly polarized, omni-directional in azimuth and hemispherical in elevation.

Magnetometer

A Geometrics high sensitivity magnetometer was used. This device used a microprocessor unit to measure a continuous frequency signal received from one tracking results in exceptional accuracy and prevents the tendency to track the centroid of the total return.

Random phased non-coherent RF transmission is used to eliminate Doppler effects. Distance measurements are based solely on transit time. Multipath energy and interference are removed by fully gated leading edge tracking. Both a 0-25 volt D.C. stable and linear analog output and a serial digital output are provided to the data acquisition system.

Gravity Meter

The gravity meter used on all Carson Aerogravity surveys is the LaCoste and Romberg Air/Sea Gravity Meter (Model S). This meter is a highly overdamped, spring-type gravity sensor. It is mounted on a gyro-stabilized platform and has associated electronics for the recording of gravity measurements. The collected data values are recorded on both paper and magnetic medium.

The LaCoste and Romberg stabilized platform air-sea gravity meter consists of a highly damped, zero-length spring type gravity sensor mounted on a stabilized platform with associated control electronics and a recording system. Inertial navigation quality gyros are used for two-axis stabilization of the platform. The control electronics are completely solid state.

Data Processing Constants

First Part

Job Name: Pacific Littoral – South, Colombia

Data Flown: April 16, 2006 through June 23, 2006

(Flight 1 through Flight 50 inclusive)

Gravity Meter:

LaCoste & Romberg Air/Sea Gravity Meter S-89

Gravity Meter Constant:	0,9979	Milligals per counter unit
Base Gravity:	977,8299	Gals
Base Spring Tension:	9258,0	Counter units

Magnetometer:

Base Magnetics:	31000	Nanoteslas

Second Part

Job Name:	Pacific Littoral –North, Colombia	
Data Flown:	June 30, 2006 through September 29, 2006	

(Flight 1 through Flight 63 inclusive)

Gravity Meter:

LaCoste & Romberg Air/Sea Gravity Meter S-89

Gravity Meter Constant:	0,9979	Milligals per counter unit
Base Gravity:	977,7406	Gals
Base Spring Tension:	9258,0	Counter units

Magnetometer:

Base Magnetics:	31000	Nanoteslas

RESULTS AND CONCLUSIONS

Data Interpretation

Sediments deposited in the basin are predominantly low-density clastic sediments (2.1 g/cm^3 to 2.4 g/cm^3). These sediments are over an igneous-metamorphic basement of high-density Cretaceous (2.6 g/cm^3 to 2.75 g/cm^3). Based on these values, the density that were used to transform the free-air anomaly into Bouguer Anomaly was 2.30 g/cm^3.

All maps in this Project were prepared using the GEOSOFT graphic system, using final grids of 1000 m. The data for Central Pacific was obtained from ANH and was acquired in 1999 by ECOPETROL.

Bouguer Anomaly and Magnetic Intensity

Figure 2 shows the Map of Bouguer Anomaly with a density of 2.30 g/cm^3.

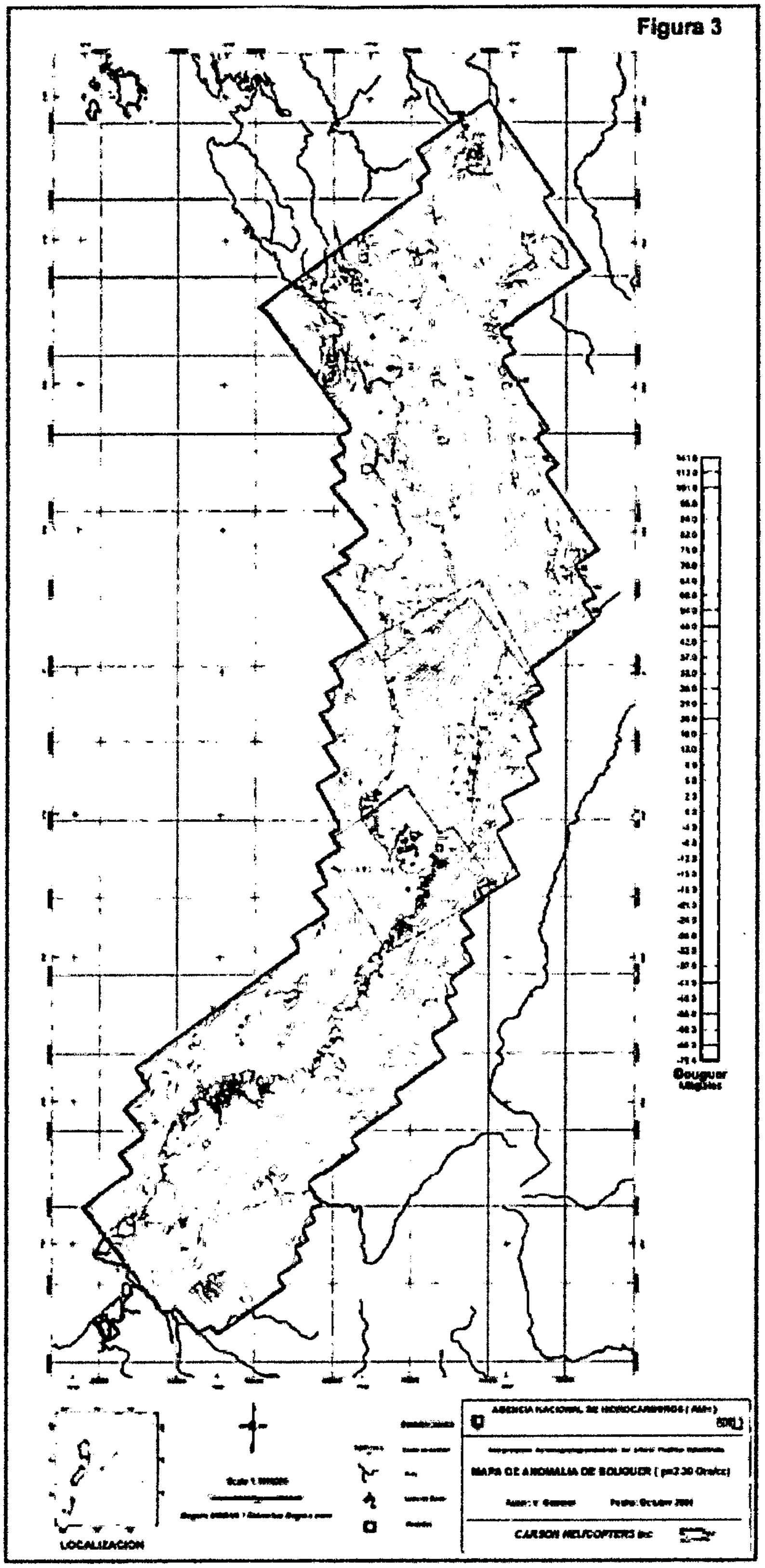


Figure 2. Bouguer Anomaly map with a density of 2.30 g/cm3.

The Bouguer Anomaly was correlated with the contrast of density existing among the Tertiary sequences and the Cretaceous Basement. This contrast of an approximate value -0.25 g/cm^3 dominates the map of Bouguer to a large extent. Grabens existing in the Colombian Pacific Littoral is perfectly defined due to their negative Bouguer anomalies with orientation N45-55E in the south to N5-10W in the north. The Bouguer gradient all along the survey, located among the graben of the Colombian Pacific Littoral and the foothill of the Western Cordillera, shows how the thickness of the Tertiary sequences are reduced, until the Cretaceous basement outcrops on the foothills. The biggest negative anomalies indicate where the biggest thickness occurs in the Quaternary – Tertiary sequences. Positive anomalies in the south and north close to the coastline with the possibility of extending inside the Pacific coast may be understood as high structures of Cretaceous basements. In the area of Buenaventura, it is possible to see that the graben is much wider and complex (San Juan Basin).

Figure 3 shows the Total Magnetic Intensity Reduced to the Pole (TMIRP). The TMIRP map shows a strong correlation with the Bouguer Anomaly, but with a much higher contents of frequency. Positive anomalies could correspond to the igneous-metamorphic units of the Cretaceous basement rocks.

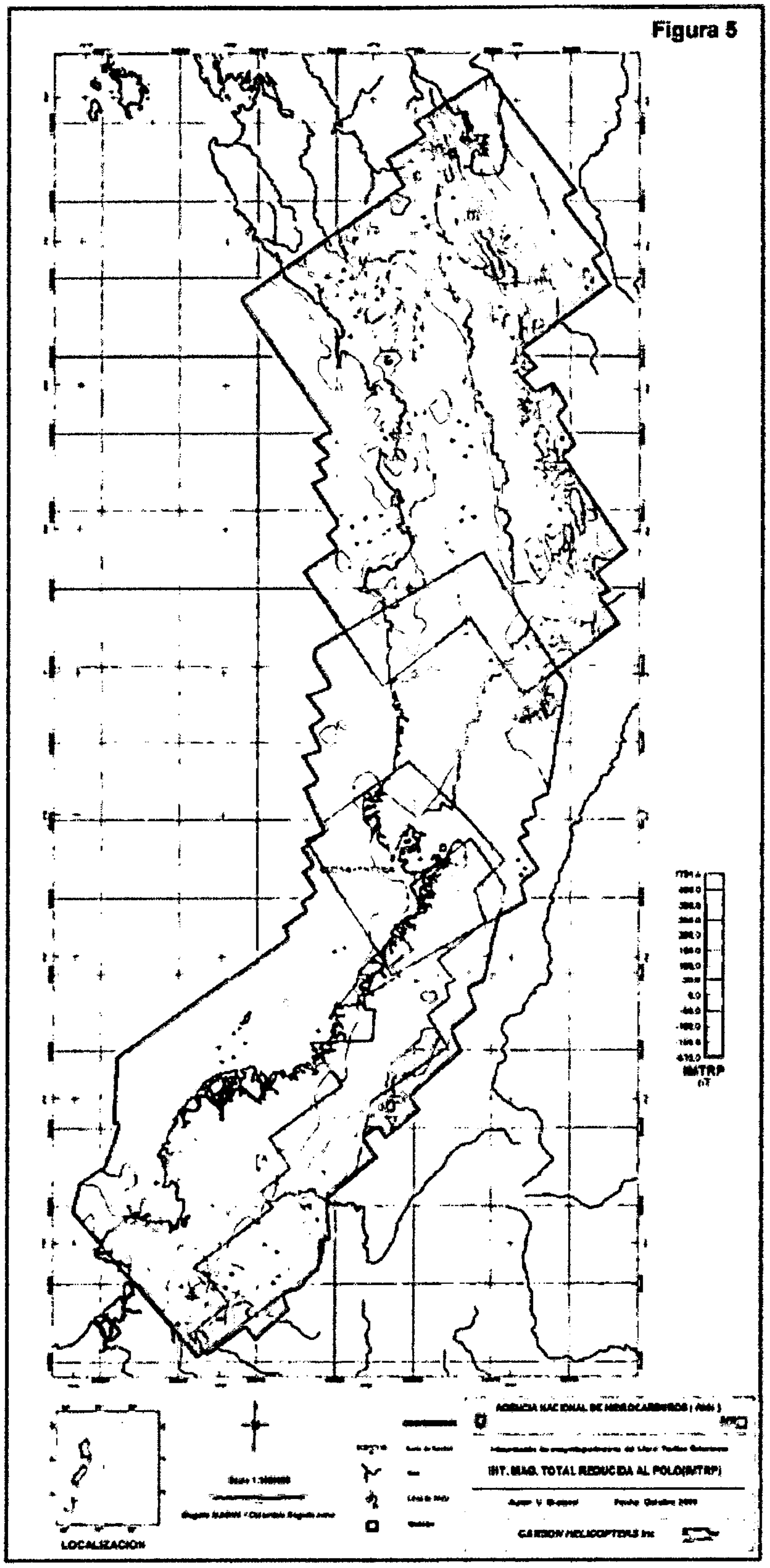


Figure 3. Total Magnetic Intensity Reduced to the Pole (TMIRP).

When analyzing the maps of Bouguer and the Total Magnetic Intensity Reduced to the Pole (TMIRP), and comparing their anomalies with the geological characteristcs of the study area, it is possible to infer that there exist a component of contrasts for magnetic density and susceptibility among the Tertiary and Quaternary sedimentary units against a basement of a complex composition of Cretaceous age. Any residual will always show contributions of basement. To avoid this problem and to estimate the gravimetric and magnetic contribution produced just by the Tertiary and Quaternary sequences, it was made a regional-residual separation with geological control. In other words, we have obtained "residual" maps that are not affected by gravitational and/or magnetic effects from sources that are below the discontinuity of density and indicated magnetic susceptibility, that is to say, the top of basement and which show only the contribution of the sedimentary cover that is over this horizon.

Figure 4 corresponds to 3D inversion of controlled residuals that by deducting the flight height, it represents the top of the Cretaceous basement referred to average level of see; and finaly Figure 5 shows the structural interpretation of the Cretaceous basement that is obtained from Figure 4.

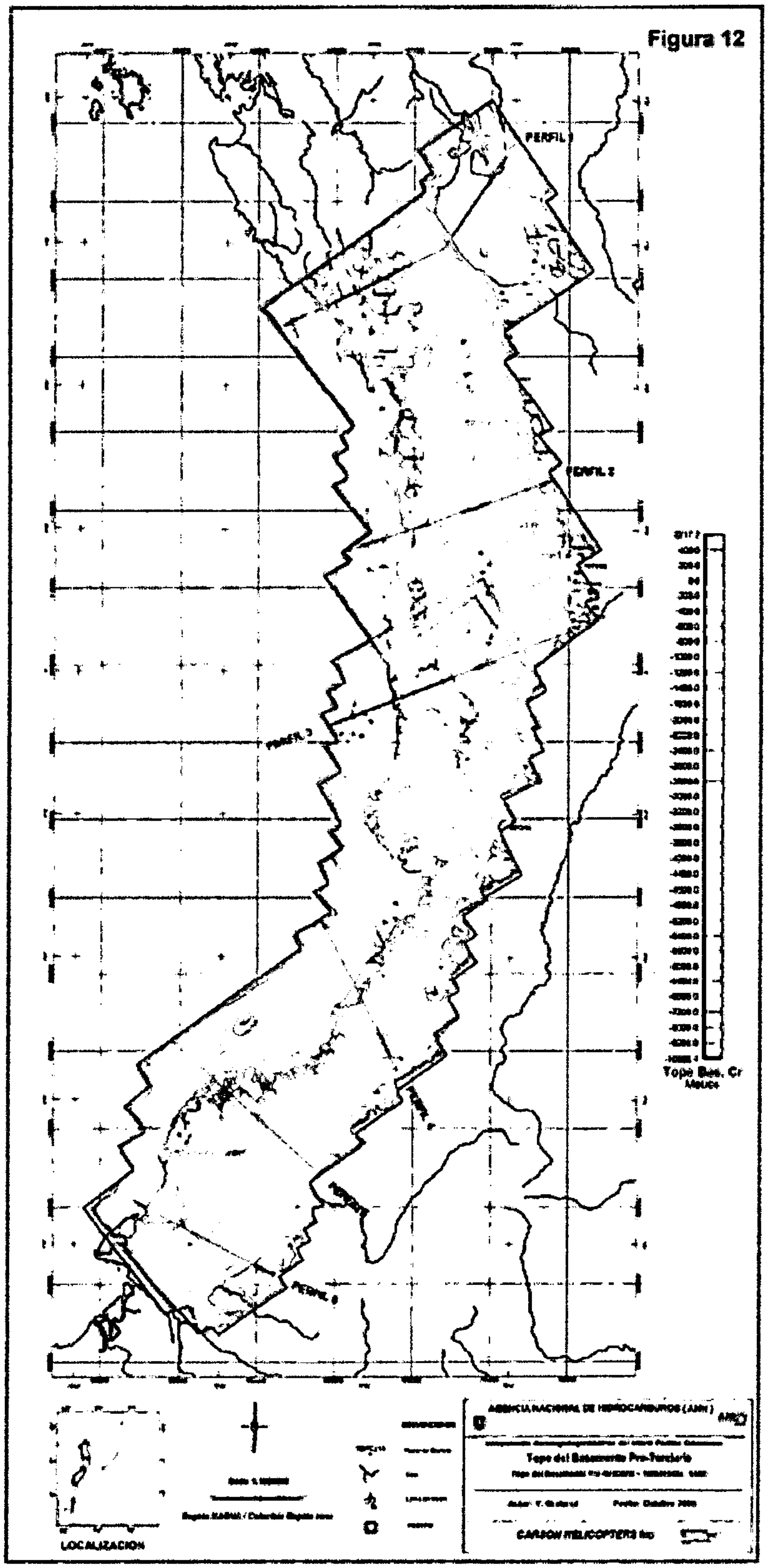


Figure 4. Top of Cetaceous basement referred to average level of see.

Map of Structural Interpretation

The map of structural contours from the 3D gravimetric inversion of the residual with geological control, constituted the basis to carry out the structural interpretation of the Cretaceous basement. This map depicts clearly not only where the biggest thickness occurs for Tertiary and Quaternary sequences, but the interpretation of the main faults and other structural characters. It is shown how this phenomenon occurs all along the foot of the Western Cordillera. The 3D inversion of Quantitative Gravimetric Residual let to detect the existence of Tertiary basins of graben type, with an orientation predominantly from north to south, in parallel to the border of the Western Cordillera. From south to north we can firstly notice the Tumaco Sub-Basin; this graben becomes wider toward Buenaventura (San Juan Sub-Basin) and narrower toward the border with the Republic of Ecuador. Toward the north of the San Juan Sub-Basin the graben is perfectly defined or Atrato Sub-Basin. The faults in the direction from northeast to southwest, possibly associated to the collision of the Pacific plate with South-American plate, locally displace not just the axis of grabens or Sub-Basins, but also the main backthrust and thrust located on the foothill of the Western Cordillera and platform border of the Pacific. The maximum thickness of Tertiary-Quaternary sediments is in the range from 7500 m to 8500 m in Tumaco and 8500 m to 10000 m in Atrato. These are enough thickness so that the black shales and fractured limestones of Formation Iro (Oligo-Miocene) generate hydrocarbons and can migrate toward nearby structures within the same basin or until structures of San Juan Basin. These big size thickness of Tertiary rocks are an indicative that the graben could have been stuffed by two sources: one eastern of the Western Cordillera and another starting from diverse accumulations contributed during the development of the structural complexity of the Colombian Pacific Littoral. The most shallow basin, with thickness of about 7000 m, is San Juan Basin. This basin is the one having the most geologic control (ECOPETROL, 2000), its biggest sedimentary development is observed toward the western and south of Buenaventura sectors (Figure 4). The thickness are important from the point of view of generation of hydrocarbons, and it should also be kept in mind that at regional level, this basin has been explored principally to the northeast of Buenaventura.

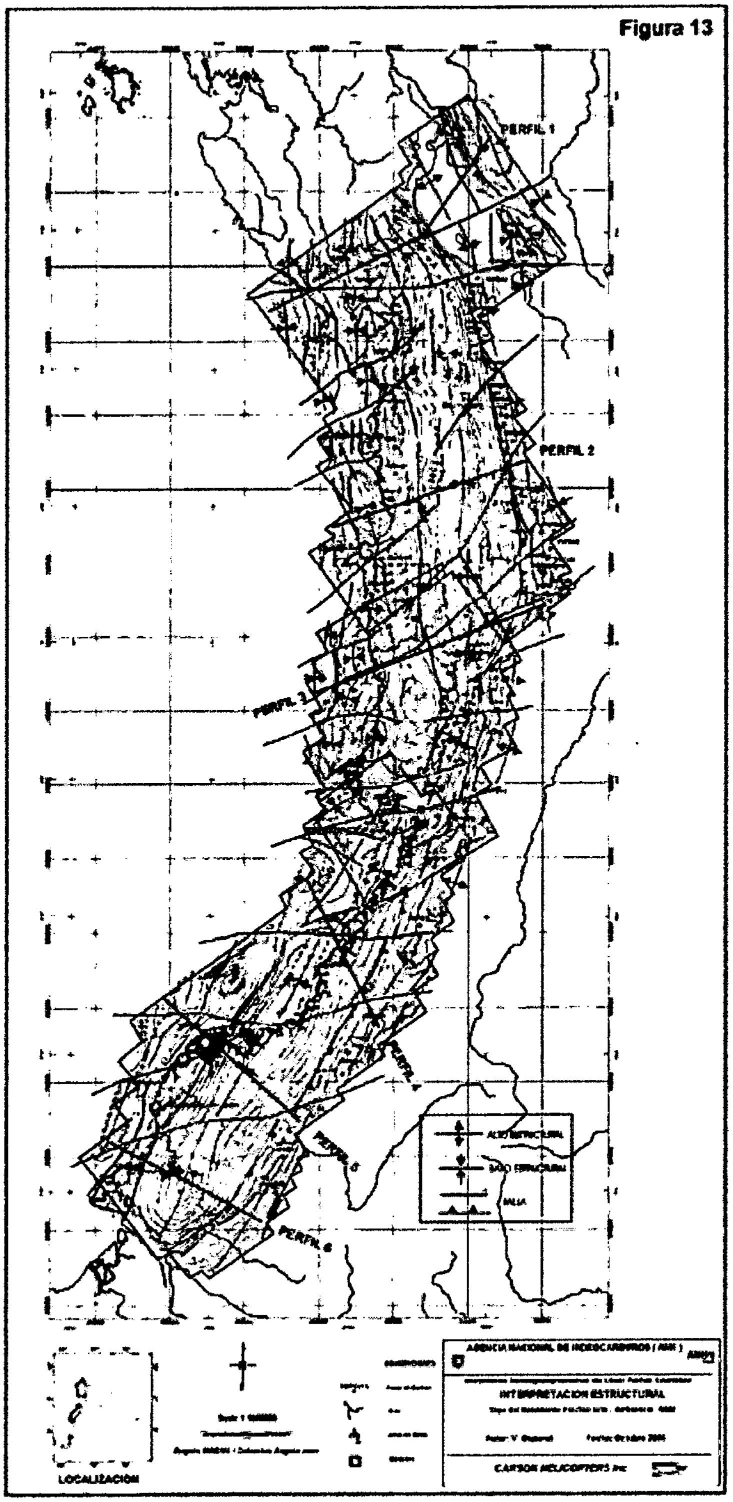


Figure 5. Structural interpretation of the Cretaceous basement.

REFERENCES CITED IN THE ORIGINAL WORK

Acosta, J.; Lonergan, L. and Coward, M. P., (2004). Oblique transpression in the western thrust front of the Colombian Eastern Cordillera, Journal of South American Earth Sciences, v 17, pp. 181-194.

ANH Mapa Geológico de Colombia. Ariana Ltd. (2004) Diaz L. and Ramos B.

ANH Registros de Pozos e Información Regional de la Cuenca del Rió Cauca. Base de Datos de la ANH.

Barrero, D. (1979). Geology of the Central Western Cordillera, west of Buga and Roldanillo, Colombia. Special Geologic Publications of INGEOMINAS. No 4. 1-75 p.

Bermúdez A. (1996). Transecta geofísica entre la Virginia y Tadó y su tectónica. Memorias del VII Congreso Colombiano de Geología, INGEOMINAS. Tomo III, pp. 68 - 78.

Buffle, R. and Blickwede (eds), The Circum-Gulf of Mexico and the Caribean: Hydrocarbon Habitats, Basin Formation, and Plate Tectonics,AAPG Memoir Nº 79, Chapter 40.

Duque-Caro, H. (1990). The Choco block in the north western corner of South America: Structural, tectonostratigraphic and paleogeographic implications. Journal of South American Earth Sciences, Vol. 3, No 1. pp. 71- 84.

Graterol, V. (2006). Informes Finales de la Interpretación Gravimétrica y Magnética de las Cuencas de Yari-Caguán, Río Cauca y Litoral Caribe Colombiano.

Meschede, M. and Barckhausen, U. (2000), Plate tectonic evolution of the Cocos-Nazca spreading center. In Silver, E.A., Kimura, G., and Shipley, T.H. (Eds.), Proc.

Moreno-Sanchez, M, and Pardo-Trujillo, A. (2003). Stratigraphical and sedimentological constrains on Western Colombia: Implications on the Evolution of the Caribbean Plate. In Bartolini C.

Nivia A. (1996). El complejo estructural Dagua, registro de deformación de la Provincia Litosférica Oceánica Cretácica Occidental. Memorias VII Congreso Colombiano de Geología, Tomo III, pp. 108 - 123.

AIRBORNE GRAVITY AND MAGNETIC SURVEY: CARIBBEAN LITTORAL, COLOMBIA – DATA PROCESSING REPORT[1]

Carson Helicopters, Inc./Aerogravity Division

www.carsonhelicopters.com/

2007

ABSTRACT

Carson Aerogravity a Division of Carson Helicopters, Inc. conducted for the Agencia Nacional de Hidrocarburos (ANH), an airborne gravity and magnetic survey of Caribbean Littoral, Colombia. Data from the airborne system are processed for acceleration, speed changes and departures from the flight reference surface made along each individual survey line. A profile is made for each survey line from the following parameters: topography, spring tension in milligals, Eötvös, GPS elevation, GPS PDOP, vertical accelerations calculated from the GPS data, average beam times "K" (i.e., "K" being a constant), and three plots of the free-air gravity with various levels of filtering. Once a line is accepted, a track plot map of the line is made. When the preliminary stage is completed, intersection analysis for all lines is performed on the parameters of gravity, magnetic and topographic surface.

OBJETIVE

Perform the airborne gravity and magnetic survey of Caribbean Littoral, Colombia.

SURVEY AREA DESCRIPTION

The area is generally defined by latitude 7 degrees 30 minutes north to 11 degrees 00 minutes north and longitude 74 degrees 10 minutes west to 72 degrees 00 minutes west (Figure 1). Gravity and magnetic data were collected at a one-

[1] Relevamiento aerogravimétrico y aeromagnetométrico. El Litoral Caribe, Colombia. Informe sobre

second-sample rate in a 7.5 × 10 km flight grid, established by ANH, for the survey.

METODOLOGY

Survey System

The airborne gravity and magnetic survey system, outlined below, was developed and patented by Franklin D. Carson and William R. Gumert in 1984 after years of extensive research and field testing. The Caribbean Littoral, Colombia survey was performed using a DeHavilland Twin Otter, N239Z, fixed wing aircraft.

Navigation

Aircraft navigation is maintained through the use of the NAVSTAR Global Positioning System, (GPS), and a real time navigation system.

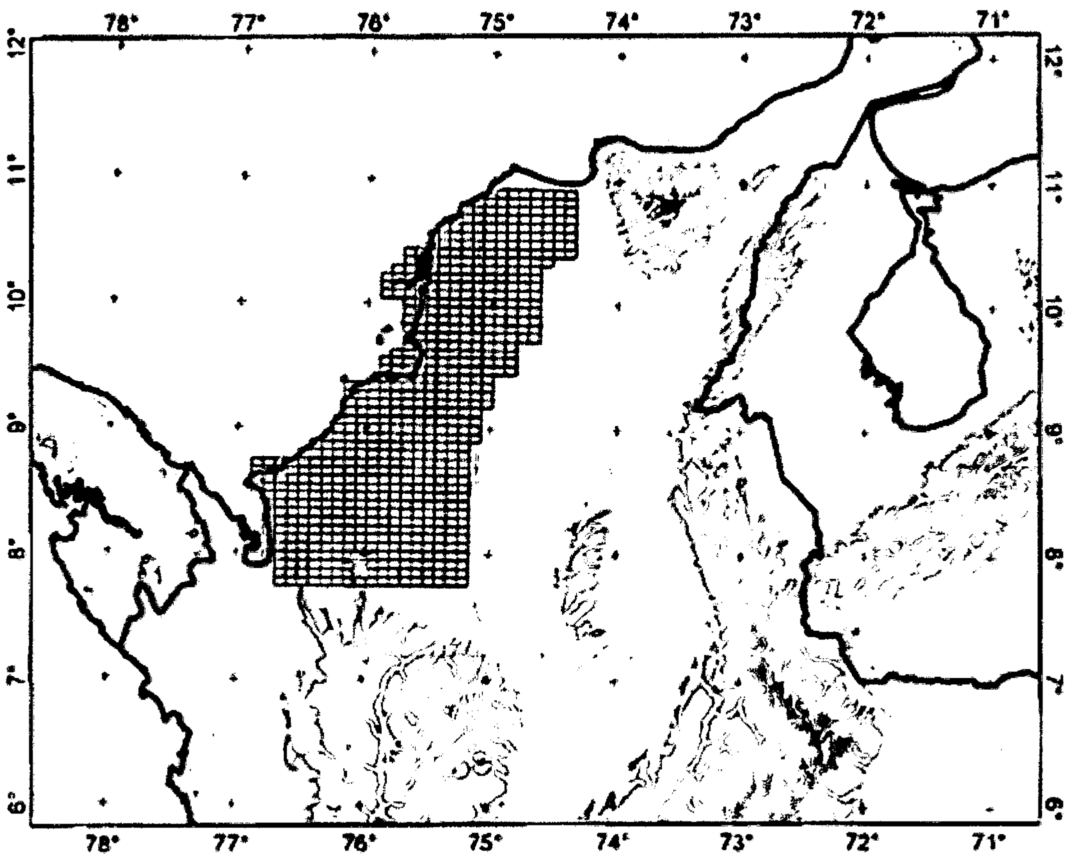


Figure 1. Survey Location Diagram.

Satellite signals are received by a single antenna contained in the RF unit mounted on top of the aircraft where it receives the maximum signal strength with minimum interface. The antenna is right-hand circularly polarized, omni-directional in azimuth and hemispherical in elevation.

The signals are received, filtered and amplified. These high frequency signals are down-converted to an intermediate frequency (IF) and then sent to the digital unit via a single coaxial interconnecting cable. This cable also provides power to the RF unit from the digital unit power supply.

The digital unit accepts the IF signal from the RF unit and converts the signal into a digital sequence using a high-speed analog-to-digital converter. Following A/D conversion, the signal is split into twelve separate channels in the digital signal processor (DSP) for code correlation, filtering, carrier tracking, code tracking and signal detection. In normal operation, each of the twelve channels will track one satellite, thus providing continuous data from eight satellites for computing position.

This navigation device displays in real time the ongoing flight path with overlay of the survey area, flight lines, and identifiers. The zoom in/out facility can display the area and survey lines. Autocentering also takes place either by manual entry or when the present position reaches close to the displayed area boundary. The new image of area and survey lines is centered on the present position.

Magnetometer

The magnetometer to be used on this survey is a Geometrics high sensitivity magnetometer. The microprocessor based unit is used to measure a continuous frequency signal received from one optically pumped Cesium magnetometer sensor mounted within a stinger under the aircraft tail section.

An automatic aeromagnetic digital compensator unit is installed in the aircraft. The AADCII is an instrument used to compensate or correct in real time for the magnetic interference caused by the aircraft itself and aircraft maneuvering in the earth's magnetic field, when using inboard mounted high sensitivity magnetometers. The compensations account for the effects of permanent magnetism, induced magnetism, Eddy currents and also removes the heading errors caused by the sensors themselves. It provides a frequency bandwidth of DC to 0.9 Hz, the frequencies of most interest to the geophysicist. The signal(s) from the magnetometer(s) are digitized faithfully without aliasing or phase distortion.

The variations of the Earth's magnetic field are recorded during flight in units of one tenth of a nanotesla at ten times per second sample rate on magnetic medium. The magnetic data is also recorded, in flight, on an analog paper strip chart for direct field monitoring. A magnetic base station, recording diurnal effect, will be set up and operated near the aircraft parking area at the airport used for the survey operations base. The magnetometer and recorder will be set up in a magnetically quiet area near this base and will be in operation during data collection times. These data will be used as a base constant comparison to the flight data acquired.

Data Recording/Data Acquisition System

Design Enterprises Model 6200C Data System is a microprocessor based Data Acquisition System for the measurement and recording of analog and digital signals. The Model 6200C System has been tailored to the application of recording airborne measurements. The use of a microprocessor design as accomplished in the 6200C results in a data system with high reliability through use of fewer parts, and the inherent flexibility with software programming. In addition, the Model 6200C offers serial I/O capability and front panel reading of digital inputs.

Altimetry

The Rosemount Model 1201F Pressure Transducer is designed to provide a highly accurate, high level DC output voltage linear with sensed absolute pressure. The excellent linearity of the output allows for direct reading or recording of a highly accurate signal without additional correction or amplification. The Model 1201F utilizes a patented low stress, "free-edge" diaphragm design and a patented capacitance measuring circuit to achieve static accuracies of ±0.1% span.

The Honeywell HG7195A radar altimeter is pulsed radar, leading edge return system that measures the closest target to the aircraft. Closed loop leading edge tracking results in exceptional accuracy and prevents the tendency to track the centroid of the total return.

Random phased non-coherent RF transmission is used to eliminate Doppler effects. Distance measurements are based solely on transit time. Multipath energy and interference are removed by fully gated leading edge tracking. Both a 0-25 volt D.C. stable and linear analog output and a serial digital output are provided to the data acquisition system.

Gravity Meter

The gravity meter used on all Carson Aerogravity surveys is the LaCoste and Romberg Air/Sea Gravity Meter (Model S). This meter is a highly overdamped, spring-type gravity sensor. It is mounted on a gyro-stabilized platform and has associated electronics for the recording of gravity measurements. The collected data values are recorded on both paper and magnetic medium.

The LaCoste and Romberg stabilized platform air-sea gravity meter consists of a highly damped, zero-length spring type gravity sensor mounted on a stabilized platform with associated control electronics and a recording system. Inertial navigation quality gyros are used for two-axis stabilization of the platform. The control electronics are completely solid state.

Data Processing Constants

Job Name: Caribbean Littoral, Colombia

Data Flown: February 28, 2006 through June 13, 2006

(Flight 1 through Flight 66 inclusive)

Gravity Meter:

LaCoste & Romberg Air/Sea Gravity Meter S-89

Gravity Meter Constant: 0,9913 Milligals per counter unit

Base Gravity: 978,15987 Gals

Base Spring Tension: 9015,3 Counter units

Magnetometer:

Base Magnetics: 34000 Nanoteslas

Data Evaluation

Data evaluation is multi-fold and begins with a video review of the field files. This review and the flight logs are examined to reveal any loss of data, out-of-tolerance information, or operational problems that may have occurred during a flight. The data are collected and recorded unfiltered in the field at a one-second-sample rate. The processing and evaluation of the data are performed on every record at a one second-sample rate.

A profile is made for each survey line from the following parameters: topography, spring tension in milligals, Eötvös, GPS elevation, GPS PDOP, vertical accelerations calculated from the GPS data, average beam times "K" (i.e., "K" being a constant), and three plots of the free-air gravity with various levels of filtering. A comparison of these plotted files with one another reveals the acceptability of a particular survey line's data.

Once a line is accepted, a track plot map of the line is made. This map, showing the location of the line in the survey area, confirms the line positioning and agreement or disagreement with contract specifications. When the preliminary stage is completed, intersection analysis for all lines is performed on the parameters of gravity, magnetic and topographic surface.

RESULTS

Computed Lengths Of Data Profiles

The Caribbean Littoral, Colombia survey consists of 79 survey lines. There are 48 gravity and magnetic lines flown at azimuth headings of either 180 or 360 degrees from north. There are 31 gravity and magnetic lines flown at azimuth headings of either 90 or 270 degrees from north.

	Gravity Data	**Magnetic Data**
Total Delivered Distance	12285,8 kilometers	15233,9 kilometers

The data are collected in 263 data profiles. There are 132 gravity profiles and 131 total magnetic intensity data profiles.

Data Profile Identification Description

Each data profile is identified by a seven-digit number (Figure 2). This number represents four distinct pieces of information:

1) Flight Direction (Figures 1 and 2)
2) Flight Number
3) Line Number
4) Reflight Number (necessitated by reflight of the line if the initial data are rejected).

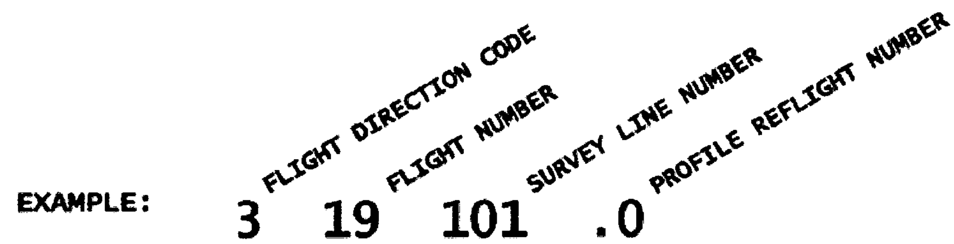


FIGURE 1
FLIGHT DIRECTION CODES

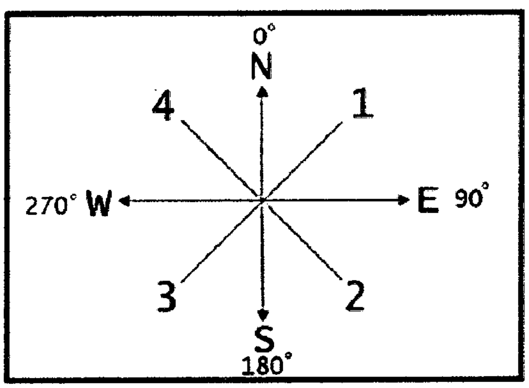


FIGURE 2
FLIGHT AZIMUTH VARIANCES

DIRECTION CODE	FLIGHT AZIMUTH
1	1° - 90°
2	91° - 180°
3	181° - 270°
4	271° - 360°

Figure 2. Data Profile Identification Description.

Gravity Data Profiles and Total Magnetic Intensity Data Profiles

Below examples of Gravity Data Profiles are shown:

PROFILE NUMBER 414101.0	NUMBER OF POINTS = 1189
TOTAL LENGTH OF PROFILE	70.2 KILOMETERS.
LENGTH OF ACCEPTED GRAVITY	70.2 KILOMETERS.
TOTAL FLIGHT DISTANCE	12285.8 KILOMETERS.
TOTAL GRAVITY DISTANCE	12285.8 KILOMETERS.
TOTAL MAGNETIC DISTANCE	0.0 KILOMETERS.
TOTAL NUMBER OF PROFILES =	132

Below examples of Total Magnetic Intensity Data Profiles are shown:

PROFILE NUMBER 418101.1	NUMBER OF POINTS = 1928
TOTAL LENGTH OF PROFILE	121.4 KILOMETERS.
LENGTH OF ACCEPTED MAGNETICS	121.4 KILOMETERS.
TOTAL FLIGHT DISTANCE	15233.9 KILOMETERS.
TOTAL GRAVITY DISTANCE	0.0 KILOMETERS.
TOTAL MAGNETIC DISTANCE	15233.9 KILOMETERS.
TOTAL NUMBER OF PROFILES =	131

Figures 3 – 7 show Free-air Gravity, Bouguer Gravity, Total Magnetic Intensity and Terrain Elevation.

Gravity and Magnetic Data Color Plates

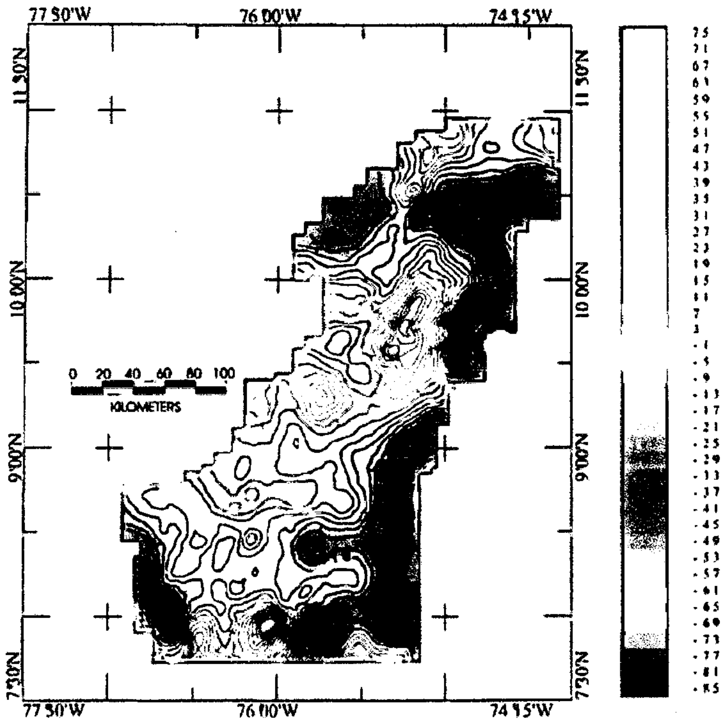


Figure 3. Free-air Gravity Final Adjusted.

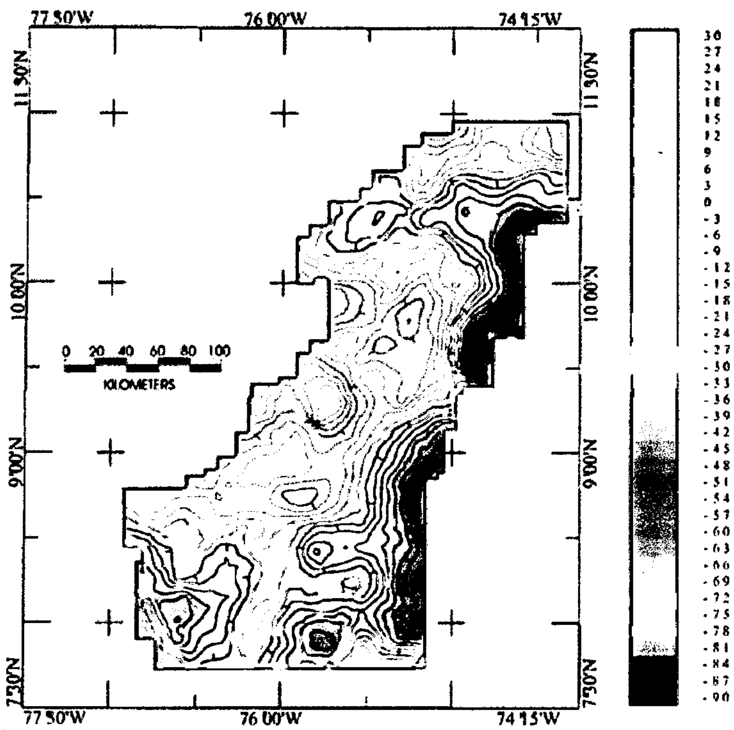


Figure 4. Bouguer Gravity 2.3 g/cm3.Final Adjustment.

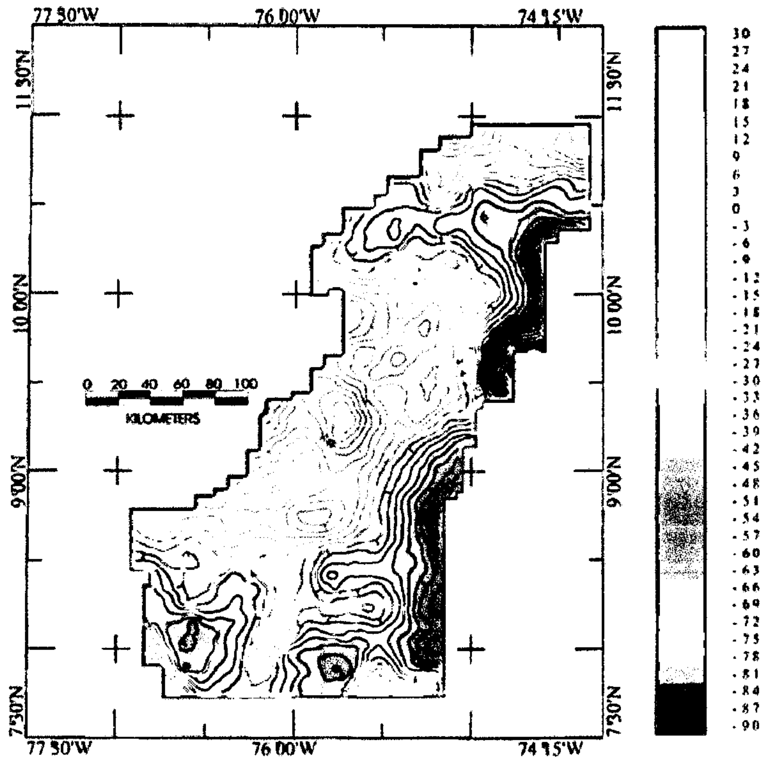


Figure 5. Bouguer Gravity 2.67 g/cm3. Final Adjustment.

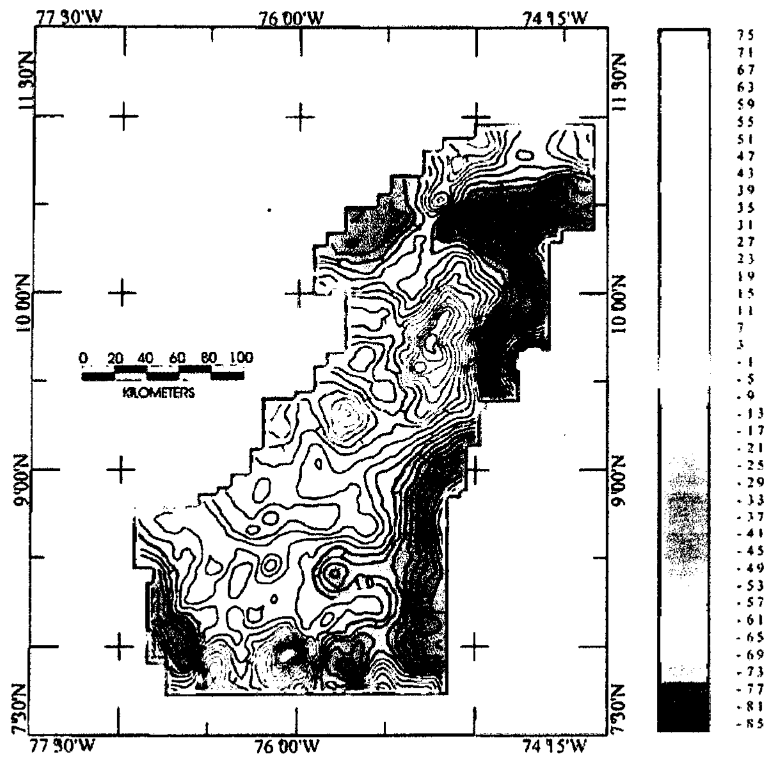


Figure 6. Total Magnetic Intensity (IGRF Removed) Final Adjusted.

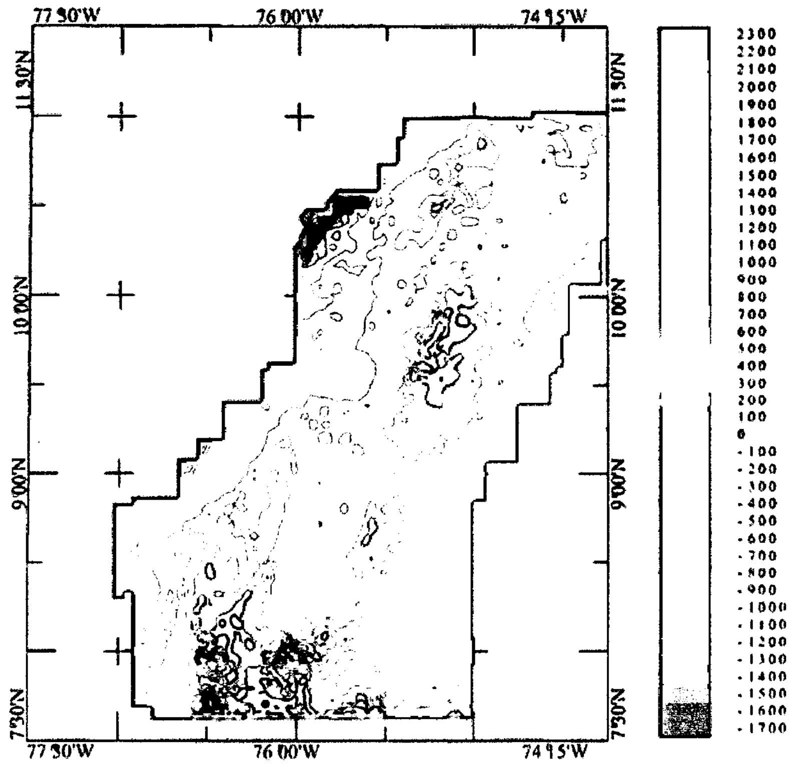


Figure 7. Terrain Elevation.

RESULTS

CONCLUSIONS

REFERENTES CITED IN THE ORIGINAL WORK

GRAVIMETRIC AND MAGNETOMETRIC SURVEY. REGIONAL COLOMBIA PROJECT. TRASANDINA SEISMIC LINE ANH-TR-2006-4A[1]

Asesoria Geofisicas de Colombia Ltda. A. G. C.

Carrera 8 No. 47-41 Int. 301 tel. 2459203

Bogotá. D.C. Colombia

agc.ltda@gmail.com

2008

SUMMARY

During the development of the Colombia Regional Project – Trasandina Seismic Line – ANH-TR-2006-4A, the gravimetric and magnetic surveys were conducted at the same time along the seismic line, whose initial coordinates are: E 763980.50 N 1496644.65, corresponding to stake No. 801, which is in Puerto Escondido municipality in Córdoba Department, and ends up on coordinate E 1124302.87 N 1244386.69, stake No. 18401 that is in Cepita municipality, Santander Department; interrupted in their continuity in Antioquia and Bolívar departments on the San Lucas Serrania Area.

The gravimetric survey was tied to the National Gravimetric Network (Agustin Codazzi Geographic Institute) transferring the value of observed gravity at Station A7CW6, located in the airport of Caucasia, Antioquia, and of GPS 0507-95, located in the Airport Palonegro of Bucaramanga, Santander. Gravimetry was carried out with two Scintrex instruments, making daily circuits, within the range of 0.2 mGal.

[1] Levantamiento gravimétrico y magnetométrico. Proyecto Colombia Regional. Línea Sísmica Trasandina ANH-TR-2006-4A. Octubre, 2008.

The magnetometry survey was carried out with three instruments GEM SYSTEM, making daily circuits that were generally within the range of 2nT.

This study gave new contributions to the knowledge about the structural configuration in the sudy area, allowed the determination of the basement average depth and its behavieur, and clarified the regional litology.

The gravimetric and magnetometric surveys were conducted simultaneously with the acquisition of the seismic data. The standard spacing applied among stations for gravimetry and for magnetrometry was 200 m. This parameter could have certain variations in a range from ±25 to 35 m because of the topographical conditions, which featured certain obstacles. The gravimetric and magnetometric surveys were conducted along approximately 356 linear kilometers, without including the tails of not measured seismic lines.

LOCATION

The study was carried out on the lines passing through Córdoba, Antioquia, Bolívar, and Santander departments. The total length was 371.6 km approximately, from stake No. 801 up to No. 9461 covering with this stretch both Córdoba and Antioquia departments; and from No. 12217 up to No. 18401 corresponding to sectors of Bolívar and Santander departments. The traced line has a S30W direction (Figure 1).

Figure 1. Layout of Seismic line.

OBJECTIVES

- To perform the gravimetric and magnetic surveys, and the processing of the information obtained in each of the geologic units involving the Sinu, San Jacinto, San Jorge, Middle Magdalena Valley, and Santander basins.
- To obtain the map of gravity anomalies as a function of the observed values of gravity, with the purpose of achieving a bigger understanding of the conditions that govern the structural configuration.
- To obtain the magnetrometry map as a function of the Total Magnetic intensity values.
- To develop a gravimetric and magnetic model by using the data collected by means of the geophysical methods above-described.

METHODOLOGY

The gravimetry and magnetrometry circuits were tied to 11 field base stations for each method, which measure less than 0.2 mGal for gravimetry, and less than 2nT for magnetometry (Figure 2).

The distance from one station to another was usually 200 m, excepting the places with adverse geographical conditions; for them data were taken in the closest station. A total of 1780 gravimetric stations and 1783 magnetometric stations were completed for an total length of 356 linear kilometers.

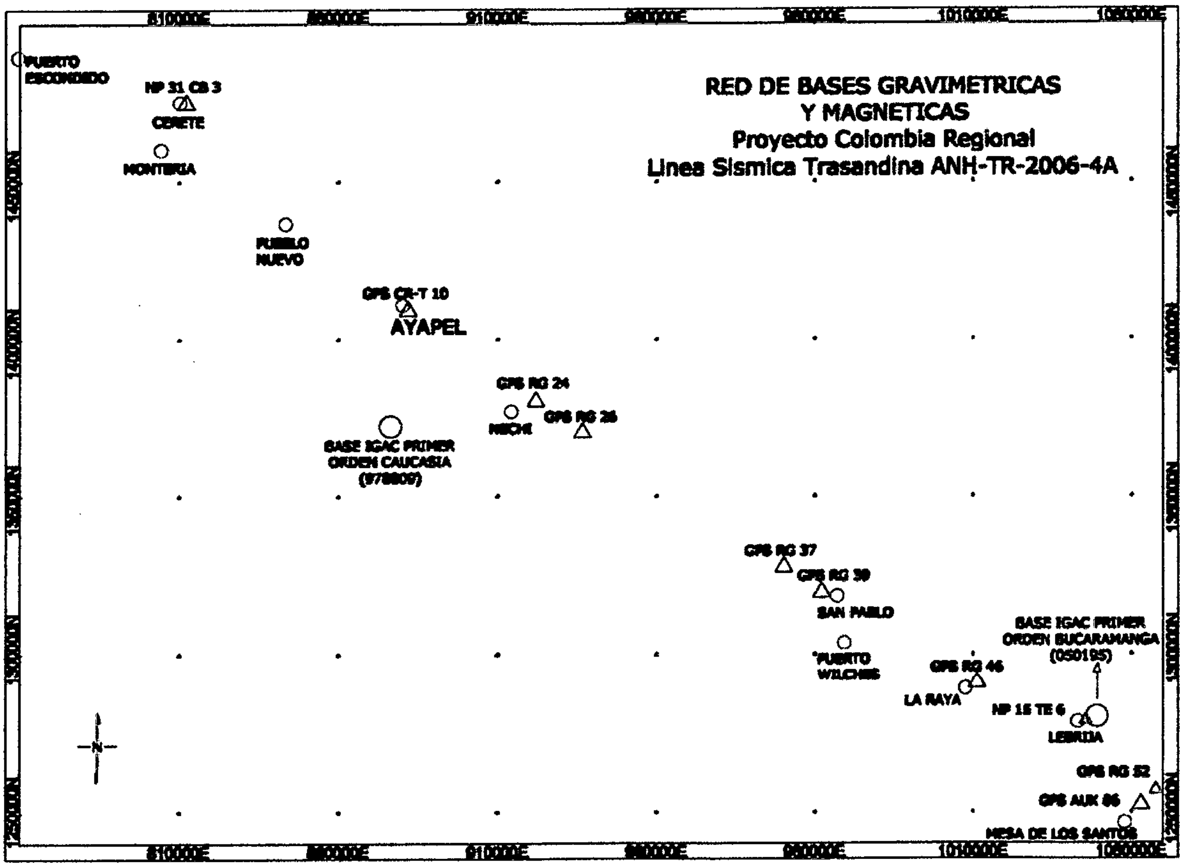


Figure 2. Network of gravimetric and magnetic field base stations.

Magnetic Susceptibility Analysis

For the Magnetic Susceptibility Analysis a SM-30 Shirt Pocket-Size instrument was used. The measurement method consists in record the magnetic susceptibility of the samples in each of its sides.

A total of 16 samples of rocks were taken for Density Analysis. These samples were analyzed in the laboratory of INGENIERIA GEOTECNICA Y LABORATORIO

LTDA. The average density value for sedimentary rocks according to the laboratory analyses is 2.36 g/cm^3 and 2.30 g/cm^3 for igneous rocks.

RESULTS AND DISCUSSION

Gravimetric and Magnetometric Maps

A set of thematic maps were elaborated including: Simple Bouguer Anomaly, Total Bouguer Anomaly, Regional Gravimetric Anomaly, Residual Gravimetric Anomaly, Total Magnetic Intensity, and Reduction to the Pole.

For the Simple and Total Bouguer anomalies a value of density of 2.67 g/cm^3 was used, which is generally used for regional studies in Colombia.

Map of Bouguer Anomaly

It is possible to notice the influence of the high level of the basement in the Monteria area, as well as the gradual differentiation of anomaly values, with a tendency to descent toward SE (Figure 3). Continuing toward the east, some of the found anomaly values are slightly higher, and they are associated to metamorphic formations outcropping in the area, and to a relatively lower basement depth.

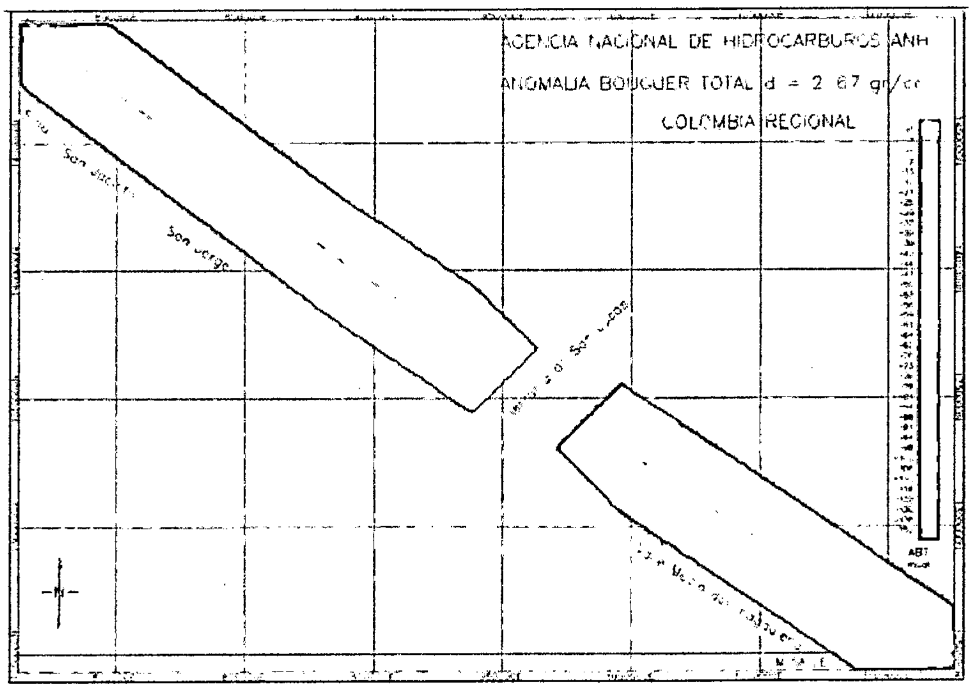


Figure 3. Total Bouguer Anomaly D=2.67 g/cm3.

Figures 4 and 5 depicts the Regional Bouguer Anomaly and Residual Bouguer Anomaly maps, respectively.

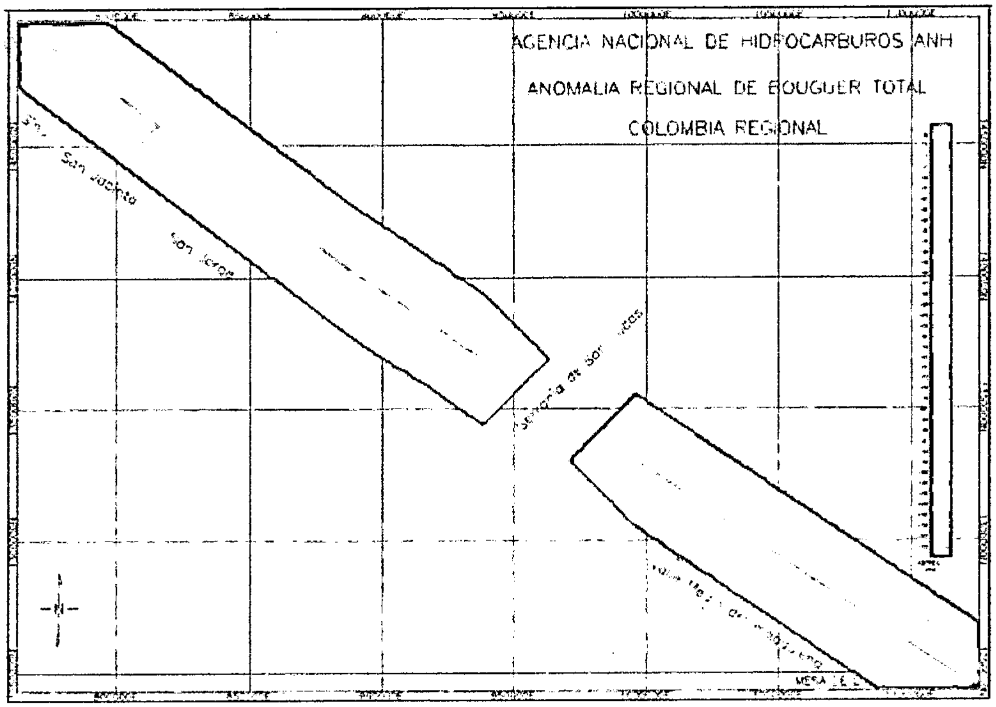


Figure 4. Regional Bouguer Anomaly D=2.67 g/cm3.

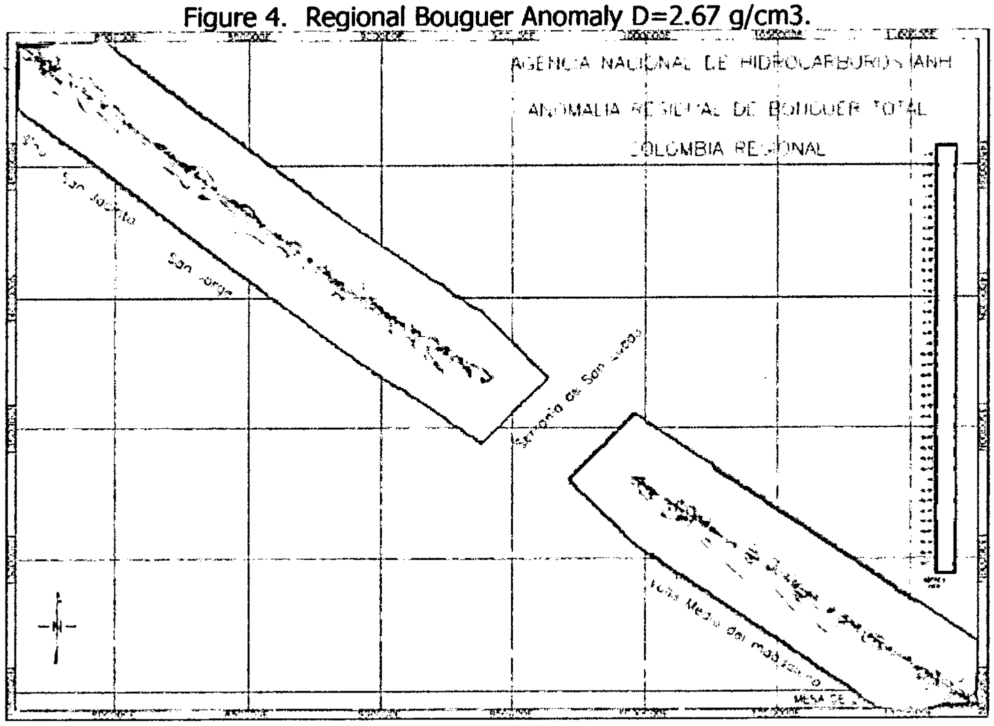


Figure 5. Residual Bouguer Anomaly D=2.67 g/cm3.

Analysis of these maps give a description of the most important aspects in each basin, as follows:

Sinú-San Jacinto

Lateral variations (west to east) of the anomaly values define a differentiation in two aspects related with the basement:

a) The density of basement tends to be reduced toward the east, since in that area the predominant basement is the continental one, with lower values of density.

b) Even though the basement may have the same density along the area, if it is more exposed or with a less thick sedimentary coverage over it, it will cause a stronger anomaly effect.

The morphology of the whole area can be defined as a very wide anticline result of compressive stress.

San Jorge

Anomaly values are observed related with the change in the basement type, passing from one of marine type, with a higher density, to a continental type, with lower values of density. The deepening of this basement toward the center of the basin implies the increase in thickness of the overlying sediment. Therefore, it will generate anomalies of a smaller value. The morphology of this basin (wide sincline) is a response to a stress generated by the compensation of the ridge area arising, and rotational component in faults that limit the basin to the west and ti the east.

Serranía of San Lucas

The increase in anomaly values toward the east is explained by the tendency of over exposure of basement toward the east. This is the area where the Serranía (ridge) itself is located. To the east side of Serranía, the tendency is inverted since it limits with the Middle Magdalena Valley Basin setting an abrupt lithologic change from igneous rock to sedimentary rocks.

Middle Magdalena Valley

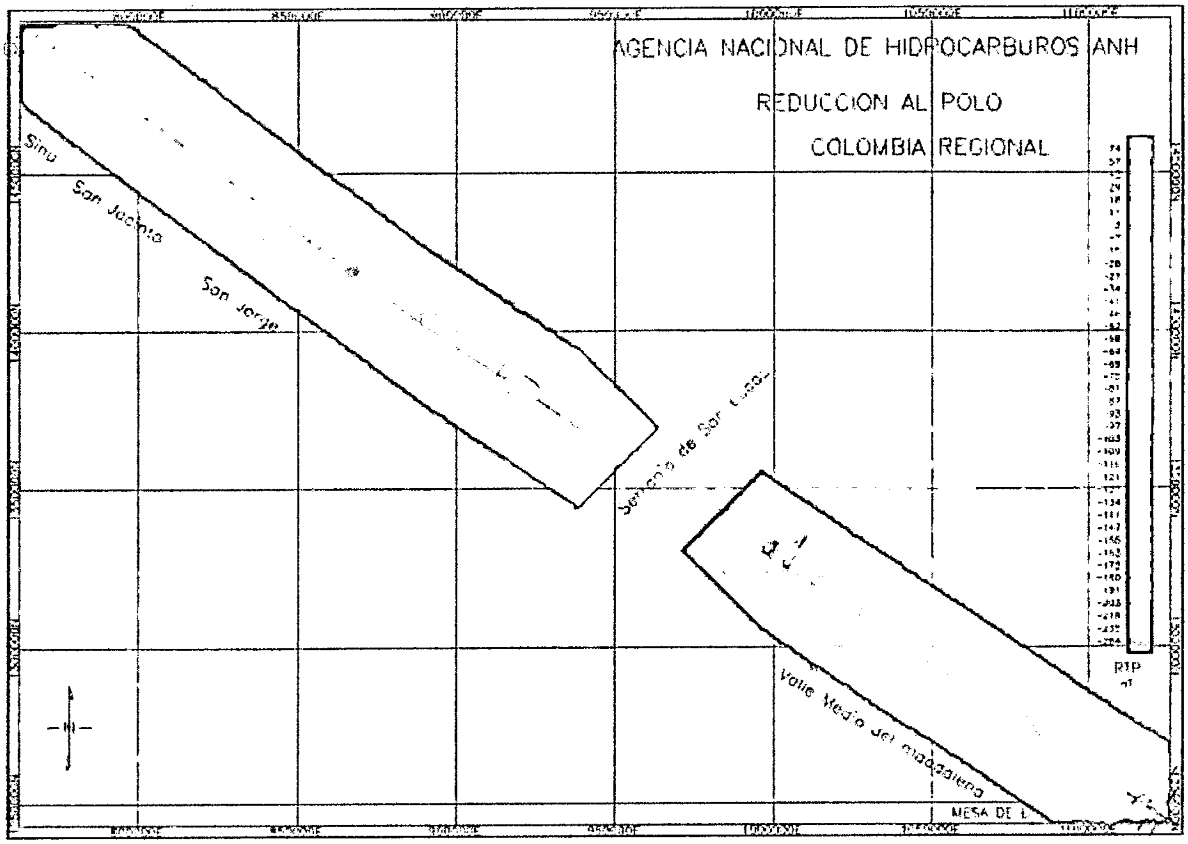
Some lower anomaly values are observed in this area. They are related with the deepening of the basement toward the center of the basin leading to the increase of overlying sediment thickness, generating anomalies of a smaller value. In contrast with the San Jorge Basin, here we can see a bigger thickness of the sedimentary column, which generates lower anomaly values. The morphology of this basin is of synclinal type, limited both to the west and to the east with very high zones, and it is probable that this geometry of the basin is a response to a compensation of such arising.

Santander

Toward the west of this basin we can find anomalies that are relatively higher than those found in the Middle Magdalena Valley Basin, probably caused by the rised rocky massif. On the eastern border of this area (end of the lines) the anomaly values are low again, what can be explained by the abrupt variations in the topography that could have caused a regional effect.

Total Magnetic Field Map

Making the correction by reduction to the pole, based on the magnetic field acquired data, the map of Reduction to the Pole was generated (RTP) (Figure 6). It is possible to observe very low values of RTP toward the coastal area, previous to the area where it is considered that the Romeral Fault System could be located, and the values of RTP slightly increase. It is also possible to see a contrast toward the beginning of the Cauca and Nechi rivers basins where values of RTP increase in a stronger way with respect to the gradual way how changed from west to east. In the western part we can observe high values of RPT with a trend to the descent toward the west. This is an area related to occurrence of metamorphic rocks.



Figures 6. Reduction to Regional Pole.

Geologic-geophysical Models

Two profiles were modeled, trying to visualize the anomalous values presented in the maps of Total Bouguer Anomaly and Reduction to the Pole. For these profiles, modeling the GM-SYS software was used.

Model 1 Profile 1 Sectors 1 and 2

The pattern of Profile 1 Sectors 1 and 2 (Figure 7), in NW-SE direction shows several structural particularities, such as: Inverse faults systems, which deform both Cretaceous and Tertiary units. This fault pattern is given as an answer to the compressive stresses generated by the crash of the continental crust with the oceanic crust. There is a crust arising that has its superficial expression toward the area of Monteria. From there toward the east, until the Romeral Fault, the crust is intercalated with materials of Cretaceous Age. The Romeral Faults System and the fault itself, present very high angles, generating a structural barrier, limiting and probably being the clearest expression of that change from continental crust to oceanic one. The geometry of San Jorge Basin is that of a wide syncline, lying toward the east. The termination of the San Jorge Basin is limited in depth by a very high angle fault, which lifts old rocks in a successive manner toward the east until the basement outcrops on the surface.

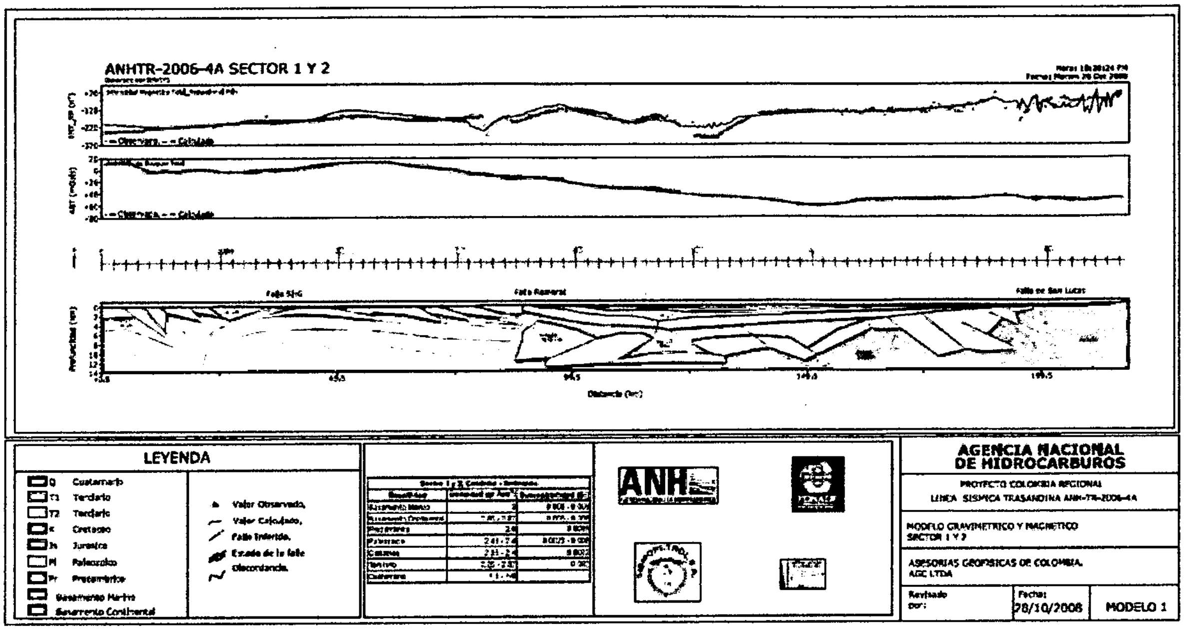


Figure 7. Model 1 Profile 1 Sectors 1 and 2.

Model 2 Profile 2 Sectors 3 and 4

The pattern of Profile 2 Sectors 3 and 4 (Figure 8), in NW-SE direction, shows several structural particularities, such as: From east to west we can observe an extinction of San Lucas Serranía limited by a fault of high angle. Following, it is possible to see the Middle Magdalena Valley Basin forming a wide syncline. In depth it has an angular discordancy among Tertiary rocks. Formations deposited pre-discordancy are deformed, and they have an anticlinal geometry. There is also a strong folding of Tertiary and Cretaceous rocks controlled by a fault with a dip slope toward the east. In the case of Santander Basin a strong change in topography takes place. This is caused by the faluts originated by the strong igneous activity toward the east and the cumulative deformation related with the dynamics of Bucaramanga Fault.

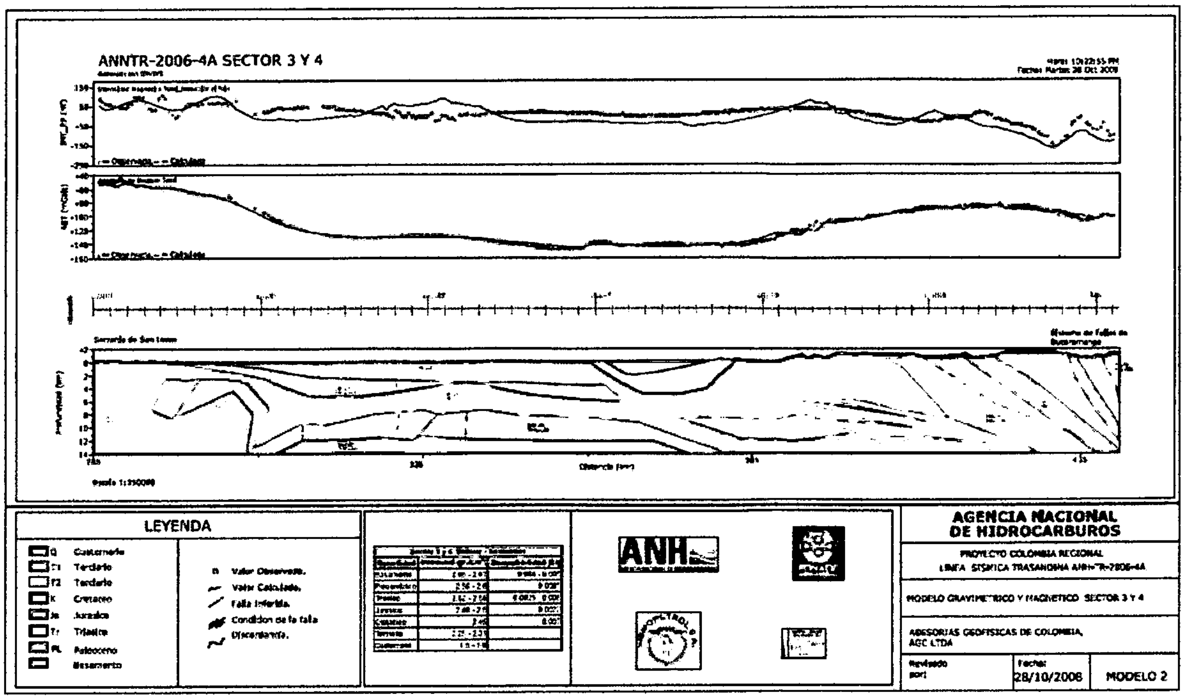


Figure 8. Model 2 Profile 2 Sectors 3 and 4.

CONCLUSIONS

- The survey was conducted with high standards of quality based on collected reliable data, which allowed to perform a processing and modeling of gravimetric data aimed to support, along with other geophysical and geologic tools, the exploration of hydrocarbons.
- The measured anomalies allow to correlate relevant structural features, such as the Romeral Faults System, Middle Magdalena Valley Basin, mineralized areas, and the change in the behavior of basement among others. According to gravimetric data, these faults and structures are displaced in some sections with respect to those, which are reported in geologic maps in a margin of about 200 meters.
- The synclinal and anticlinal structures are correlated in spite of the scale of the study, as well as the most regional aspects, using the geologic maps.
- The achieved results show that the integration of gravimetry studies with other disciplines both geophysical and geological is a good tool for the exploration and knowledge of oil basins; therefore, it is recommended to continue with this working methodology.

REFERENTES CITED IN THE ORIGINAL WORK

GM-SYS, Manual. Grav/Mag Modeling Software. Geophysical Associates Inc.

INSTITUTO GEOGRAFICO AGUSTIN CODAZZI (1998). Gravimetria 1998. Santafé de Bogotá D.C. 319 p.

Logachev, A. A. and Zajarov, V. P. (1978). Exploracion Magnetica. Ed. Reverte S.A. Barcelona. 346 p.

Mironov (1985). Gravimetria. Ed. Reverte, Barcelona. 405 p.

Oasis Montaj v6.3, TUTORIAL and USER GUIDE. Geosoft Inc. 2006.

SCINTREX. Manual Operation CG-3/3M Gravity Meter.

SCINTREX. Manual Operation CG-5 Autograv System.

SM-30 Manual Shirt Pocket-Size Magnetic Susceptibility Meter.

Smith, P. (1931). Introduccion al estudio de la Gravimetría y Magnetometría. Imprenta Revels. 245 p.

INVENTORY AND EVALUATION OF MICROPALEONTOLOGICAL INFORMATION IN SEDIMENTARY BASINS OF COLOMBIA (PALYNOLOGY CASE). FINAL REPORT.[1]

SMITHSONIAN TROPICAL RESEARCH INSTITUTE-STRI
www.stri.org

2008

SUMMARY

The palynology has been a powerful tool in the oil exploration in continental and transnational sedimentary basins. It has been applied by different national and foreign companies during the oil history of the country. Nevertheless, currently we have not clarity about the quantity and quality of the palynological information available in Colombia. Therefore, the palynologycal information available in EPIS (Exploration and Production Information Service – ANH) and other published sources were revised. The collected information was evaluated and filtered in the levels of its importance and biostratigraphic quality. Later on, it was introduced into a database and taxonomically updated. The information evaluated as biostratigrafically important was analyzed by using the method of optimization with restrictions-CONOP with the purpose of obtaining an ideal sequence of biostratigraphic events per basin, which is the base for the biostratigraphic zonation.

Just a 5% of the wells drilled in Colombia has any palynologycal study (527 wells), and most of them are in the Eastern Llanos Basin. The average of sampling is around 300 feet per sample, very far from the modern necessities of the industry, which require samplings of 30 feet/sample.

[1] Informe final del inventario y evaluación de la información micropaleontológica en las cuencas sedimentarias de Colombia (caso palinología). Panamá, octubre, 2008.

Less than 10% of the data comes from nuclei or sections of surface, the majority comes from refuse material. More than 1952 species have been used; nevertheless, most of them are informal. They have been only identified at genus level or represent species from tempered zones, which never have been reported in the tropic. Seven of the 24 Colombian sedimentary basins had an important information for the quantitative biostratigraphic analysis :Llanos, Middle and Upper Magdalena Valley, Eastern Cordillera, Catatumbo, Caguán-Putumayo, and Guajira. A total of 96 sites, 85 of which are "ditch cutting", were processed by means of CONOP, in order to produce an optimal sequence of palynologycal events per basin.

INTRODUCTION

The precise knowledge of the quantity and quality of the palynologycal information generated by the industry is fundamental. In order to achieve this objective, an intensive search of all of the palynologycal information that is archived was carried out in EPIS. Likewise, all of the publications in journals or books were revised in order to find paleopalinological information. The evaluation of the quality and quantity of all collected information was executed for each basin. An initial filter of quality permitted to determine what information might be useful for the biostratigraphic analysis. The palynologycal information stated as important was quantitatively analyzed. For this purpose the method of optimization with restrictions-CONOP (Kemple et al., 1995) was used. This was carried out with the purpose of finding, for each basin, the most optimal palynologycal sequence. That is to say, the sequence of events of the first and last appearances of morphospecies, that theoretically represents the minor contradiction in its order with respect to the order found in each one of the wells/sections that were used for the analysis. This sequence is the base for any biostratigraphic zonation.

METHODOLOGY

Five stages were executed in order to achieve the results proposed in the project:

a) Consultation of the palynologycal information available in EPIS, as well as the one published in articles, books, and congresses.

b) Revision y evaluation of the palynostratigraphic importance and quality of collected information. For that purpose five parameters were defined: the report must have the stratigraphic location of the sample with palynology; the number of samples in the well /section must be greater than 10; the density of the interval of sampling (average of feet per sample) must be less than 300 feet; the reported species must surpass 30; and at least a 50% of the reported species must be formal.

c) Systematization of the information with biostratigraphic relevance and taxonomic revision of the systematized information. The information of each site, which passes the initial filter of the second stage, was digitally entered into a database, that was built by using MySQL software. This database contains the name of each site, its geographical coordinates, depths of sampling, found species, and relative or absolute abundance of each one of them. All of the taxonomic assignments entered into the database were compared with a general dictionary of species in order to find all of the possible synonyms, and depurate the taxonomic information.

d) Quantitative processing of the palynologyc information by using the CONOP technique. The wells that had a number of intervals of sampling greater than 20, and a density of sampling less than 100 feet were considered as biostratigraphically relevant for the quantitative analysis.

e) Zonzation of the respective CONOP sequence per basin.

MySQL database

The system is divided in 2 main parts:

- An administrator of relational databases
- A access client

For the elaboration of databases and access client, Open Code technologies were used (Open Source, 2008). MySQL version 5.1(2008) installed upon RedHat Enterprise Linux (RHEL, 2008) platform was used as administrator of relational databases. PHP (2008), 2.2 (2008) server version was used for access client. The access client was programmed using the platform and CakePHP libraries version 1.2 (2008).

RESULTS

The results obtained in this work are divided in two parts. General results, which refer to the ones obtained in a simultaneous way for all of the basins, and particular results or per basin that were obtained by means of CONOP process.

General Results

A revision of approximately 3830 files was carried out. A total of 51 publications with palynologyc information was revised. Table 1 presents the general statistics for each one of the sedimentary basins.

Table 1. Final statistics referent to the palynologyc information for each one of the sedimentary basins. AMA: Amagá, ANP: Non-prospective area, CAG-PUT: Caguán-Putumayo, CAT: Catatumbo, CAU-PAT: Cauca-Patía, CES-RAN: Cesar-Ranchería , CHO: Chocó ,CHO-OFF: Chocó offshore, COL: Colombia, COR: Eastern Cordillera, GUA: Guajira , GUA-OFF: Guajira offshore, LLA: Llanos, CAY: Los Cayos, PAC-PRF: Deep Pacífico, SINSJ: Sinú-San Jacinto, SIN-OFF: Sinú offshore, TUM: Tumaco, TUM-OFF: Tumaco offshore, URA: Urabá, VIM: Lower Magdalena Valley, VMM: Middle Magdalena Valley, VSM: Upper Magdalena Valley, VAU-AMA: Vaupés-Amazonas."Sin": Without available information, EXT: Abroad, which is not a part of the division of basins because of being outside the territorial limits but quite close to the Catatumbo Basin. *1: ANH (2007), http://www.epis.com.co/, 2: EPIS, other sources

BASIN[1]	TOTAL WELLS[1]	PALYNOLOGY WELLS[2]	No. SPECIES	No. SAMPLES	DRILLED FEET	AVERAGE FEET/SAMPLE
AMA	0	0	0	0	0	0
ANP	12	. 2	0	48	8440	193
CAG-PUT	374	27	147	862	70049	73
CAT	850	14	407	762	49452	90
CAU-PAT	5	1	0	38	3910	103
CAY	2	0	0	0	0	0
CES-RAN	57	3	186	237	9426	105
CHO	5	1	0	61	9449	155
CHO-OFF	0	0	0	0	0	0
COL	0	0	0	0	0	0
COR	146	28	537	1490	125574	248
GUA	29	6	272	431	50680	258
GUA-OFF	48	5	272	175	26658	638
LLA	1506	206	1052	6125	549902	157
PAC-PRF	0	0	0	0	0	0
SIN-OFF	19	4	170	60	46798	995
SIN-SJ	160	5	170	74	17485	352
TUM	2	0	0	0	0	0
TM-OFF	3	2	0	23	17238	762
URA	5	0	0	0	0	0
VAU-AMA	4	3	75	62	3236	178
VIM	271	12	47	215	53921	395
VMM	5699	118	341	2638	456405	287
VSM	1210	90	447	1924	210755	132
TOTALES	**10407**	**527**	**1952**	**15225**	**1709378**	**301**

Table 1 shows that considering all wells, just approximately 5% present palynologyc information. Out of them, the the Eastern Llanos Basin represents approximately a 40%, followed by the Middle Magdalena Valley and Upper Magdalena Valley basins with 17% and el 12% respectively. Nevertheless, with respect to the quantity of drilled feet, a more equitable situation is presented between the Eastern Llanos and the Middle Magdalena Valley basins, where the first one represents approximately 32% and second one 26%. Figure 1 features the data of Table 1 with respect to the wells with palynologycal information.

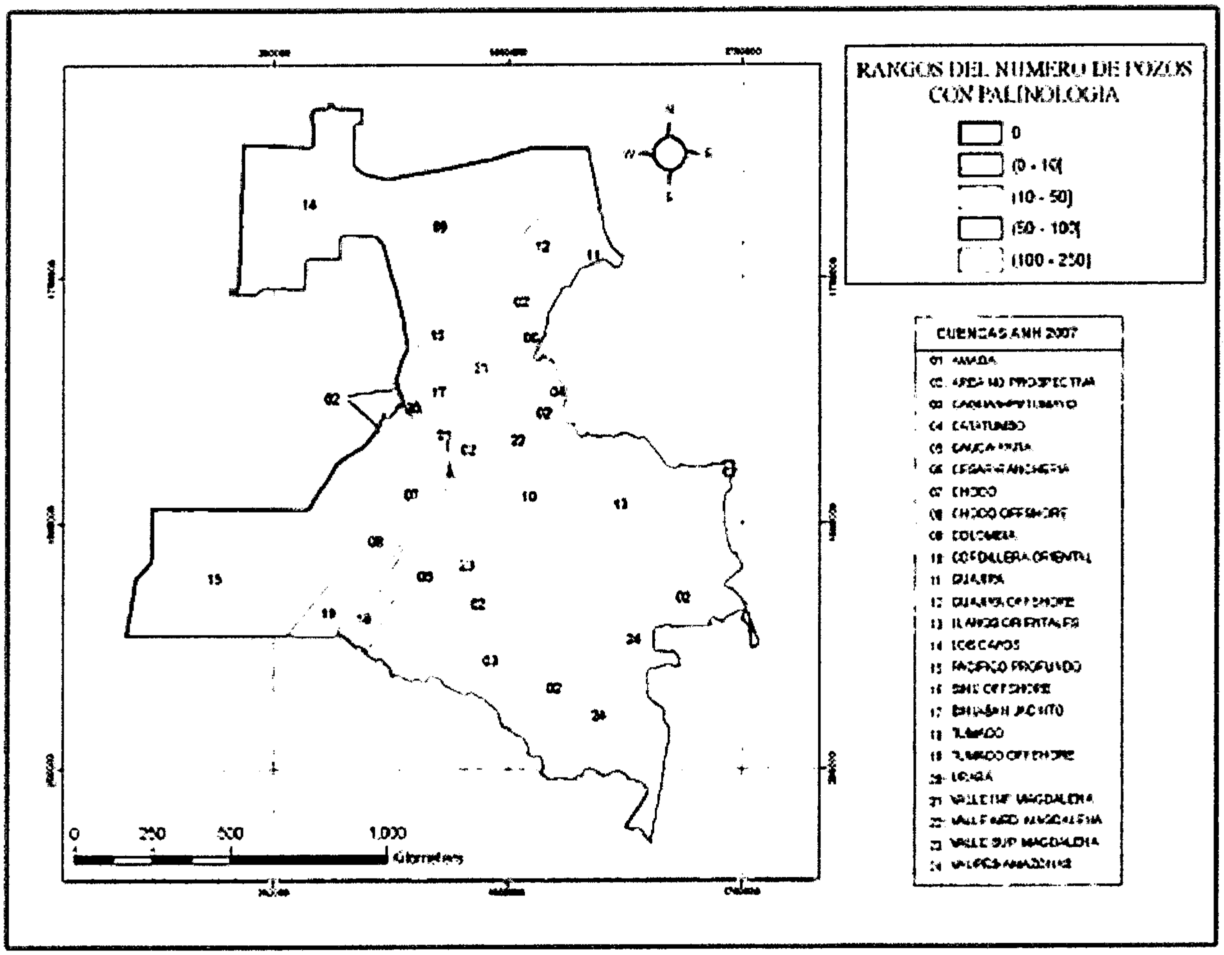


Figure 1. Schematic map of the sedimentary basins with palynologycal information and the number of wells in the range of each one of them. Note that the Llanos Basin and Middle Magdalena Valley Basin, followed by the Upper Magdalena Valley Basin are the ones with the greatest quantity of wells with palynologycal information.

Results per Basin

In this section, only basins with at least one well or section, evaluated as important for the biostratigraphical purposes, are included. Out of 24 basins eight were appropriate for the application of optimization with restrictions, and two basins presented only one well/section with biostratigraphical importance. The first 8 correspond to the Cagúan-Putumayo, Catatumbo, Eastern Cordillera, Guajira, Guajira offshore, Eastern Llanos, Middle Magdalena Valley, and Upper Magdalena Valley basins. The second ones correspond to the Cesar-Ranchería and Vaupés-Amazonas basins. Nevertheless, the Guajira and Guajira offshore basins were integrated into a unique one because independently they had a low quantity of wells leading to a decrease in the local biostratigraphical resolution.

As an example of processing lets consider the results for the Caguán-Putumayo Basin.

<u>Caguán-Putumayo Basin</u>

Four wells were selected for the process of optimization with restrictions-CONOP, located to the west end of the basin (Figure 2).

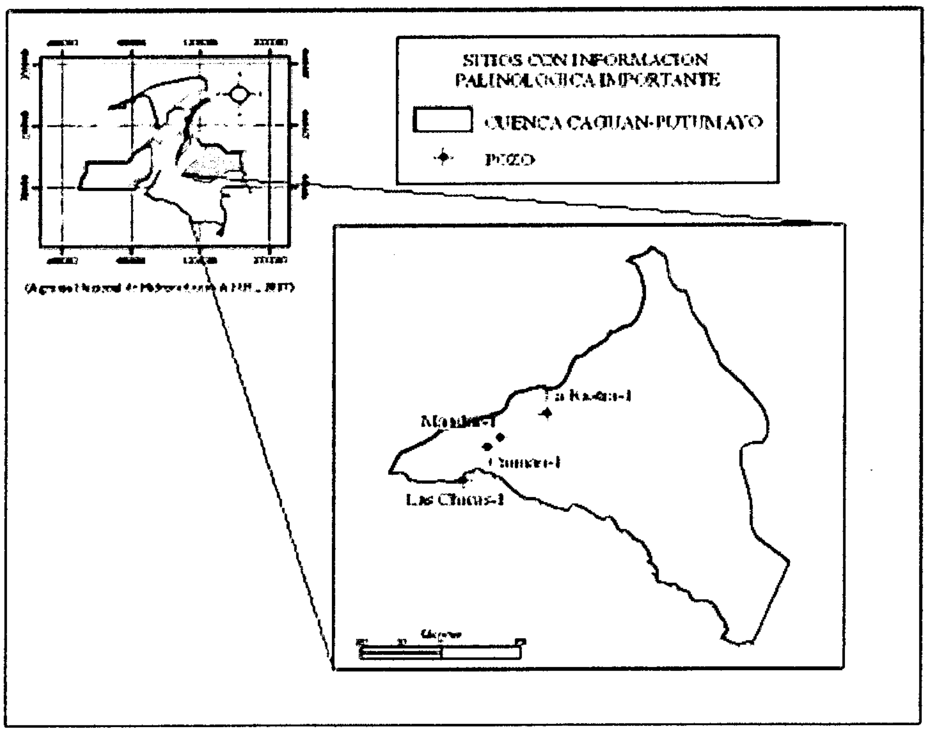


Figure 2. Location of the Caguán-Putumayo Basin and the wells for CONOP.

The total number of species contained in the four wells was 147, decreasing to 50 for CONOP after the taxonomic filter. After the data processing, the most optimal sequence was obtained. The order of First Ocurrence FOs and Last Ocurrence LOs is presented in a table where the name of species, the type of each event, the order of CONOP solution (optimal order) are presented. The greater is the number of event, the younger it is. Finally, the minimum and the maximum values, corresponding to the confidence interval of 5% are presented. These ones indicate, for each event, the positions that the value of optimal order would have related to the defined level of confidence. In other words, it indicates the level of variation of the position of each event with respect to the most optimal position.

Zonation

Very few palynologycal zonations have been proposed for Colombia. The first proposed zonation (Van der Hammen, 1957 a, b) assumed that the fluctuations of certain groups of pollens and spores are a product of regional climatic variations. Germeraad et al. (1968) published an important research, which contained a lot of information about Venezuela and some information about Colombia. This is basically the zonation used in Colombia for the Cenozoic period for the last 40 years. Germeraad et al. (1968) established 49 species, which are basically the pillar of the palynologycal advisory work of the last decades. Later on, Muller et al. (1987) produced a revised version of the zonation of Germeraad, and included the Cretaceous period, Jaramillo et al. (2005) proposed a zonation for the Middle and Superior Paleocene of the Llanos Foothill, using geographical correlation.

In this work we analyze the results of the optimization with restrictions, in order to carry out the zonation for each basin. The calibration of most of these zones is very uncertain yet, because the pollen is not a tool of calibration in the international geological time scale (Gradstein, 2004). For that purpose multidisciplinary studies are required. They include macrofossils, microfossils, isotopes, and magnetostratigraphy, which may calibrate the pollen.

As an example we present the results of zonation for Caguán-Putumayo Basin as follows:

100 biostratigraphic events were used in this basin. A mismatch is clear, which separates the palynomorphs of Cretaceous from palynomorphs of the Cenozoic period. The lack of relevant events and the width of the zones, which could be established, indicate the poor palynologyc knowledge of this basin. The distribution of events can be provided in the following zones:

***Zone CP-1* (Turonian-Coniacian)**

The top of the zone is defined by the LO of *Droseridites senonicus.* Other events within this zone include the FO of *Alisogymnium euclaense* and *Dinogymnium acuminatum* (Figure 3). Nevertherless, the effect of border is big, and it is made evident because of the great quantity of FOs associated to this zone. The calibration of this zone might indicate the Turonian-Coniacian (Muller et al., 1987).

***Zone CP-2* (Santonian-Maastrichtian)**

The top of the zone is defined by the LO of *Dinogymnium acuminatum.* Within this zone there are the LOs of *Foveotriletes margaritae, Alisogymnium euclaense,* and *Hamulatisporites caperatus.* The age of this zone might be between the Santonian and the Maastrichtian, even without reaching the youngest parts of the Maastrichtian, because there were no typical taxa indicators of the top of the Maastrichtian, such as *Echimonocolpites protofranciscoi.*

***Zone CP-3* (Oligocene)**

The top of the zone is defined by the LO of *Cicatricosisporites dorogensis.* The zone has abundant FADs, product of the gap of the taxa of the Cenozoic, and those of the Cretaceous. This gap may be related to a discordance, or a great segment of the stratigraphic column without palynologycal information (because of lack of study, or sterile rocks). Important events in this zone are the FOs of *Magnastriatites grandiosus, Perisyncolporites pokornyi, Bombacacidites brevis, Perfotricolpites digitatus, Crassiectoapertites columbianus, Psilatricolporites costatus, Catostemma type,* and the LOs of *Mauritiidites franciscoi pachyexinatus, and Retistephanoporites angelicus.* To the top of the zone, there is a great quantity of LOs, that is a product of the border effect by the end of a section (Foote, 2000). The age of this zone is considered Oligocene (Muller et al., 1987).

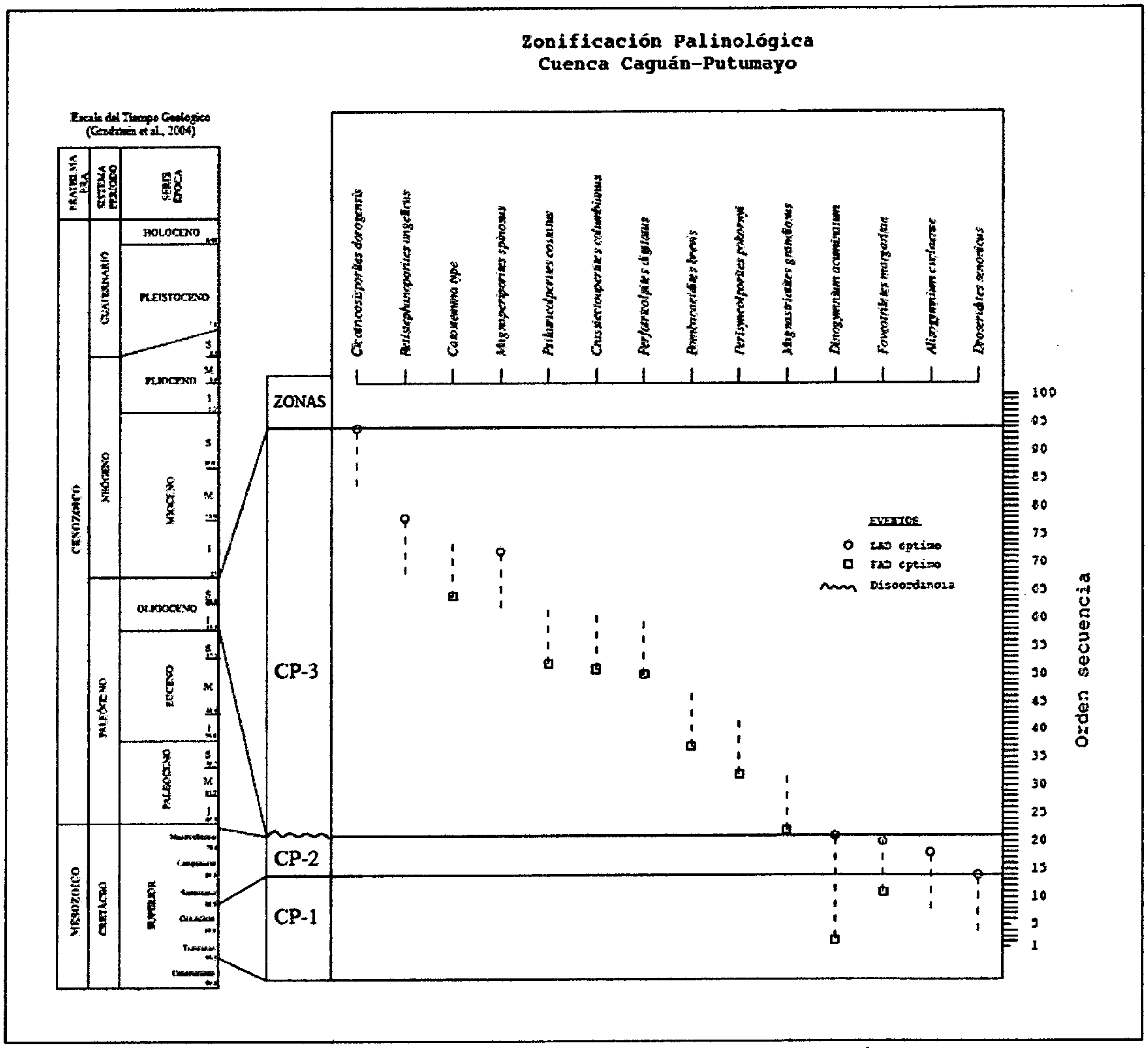


Figure 3. Zonation of the obtained sequence by means of CONOP for Caguán-Putumayo Basin.

CONCLUSIONS

1. The number of drilled wells with palynologycal information represents a considerably low percentage (<10%) with respect to the total number of drilled wells.

2. Generally, there is a low density of sampling (in average, every 300 feet), many times with short stratigraphic intervals.

3. There are very few samples of outcrops or nuclei, less than 10% of the palynologycal collected information.

4. The greatest part of the samples, as it is registered in EPIS, has qualitative determinations (presence/absence, categories of abundance rare/frequent, or very low count: less than 50 grains per sample). Less than 10% of the sites has qualitative data, with a count surpassing at least the 150 grains per sample.

5. There is a great quantity of informal species. Nevertheless, there is no their morphological description, photographic illustration, nor physical location in the palynologycal plate. These taxonomic determinations are not useful in the biostratigraphic studies.

6. More than 50% of the Colombian sedimentary basins do not have palynology of biostratigraphic significance.

7. Out of nine basins, that have important biostratigraphic information, seven are inside an eastward of the Magdalena River hydrographic Basin.

8. The Eastern Llanos Basin has the greatest quantity and best quality of palynologycal information. It is followed in order by the Middle Magdalena Valley, Upper Magdalena Valley, Eastern Cordillera, and Catatumbo basins. Other basins, such as the offshore, both Pacific and Atlantic, the Lower Magdalena Valley, and Guajira have very scarce and low quality palynologycal data, in spite of the huge potential that the palynology might have as a biostratigraphic and paleoenvironmental tool in these basins.

9. For seven of nine basins with important palynologycal information it was possible to determine the most optimal sequence of palynologycal events of first and last appearances. The events of last appearances (LADs) in each one of the sequences represent a greater consistency than the events of first appearances (FADs) with respect to the order of events, as it is expected.

10. The zonations obtained for each one of the nine basins, derived from the ideal sequences, generally is of low resolution, comparable to the zonation of Germeraad et al., produced 40 years ago. In other words, the palynographic and biostratigraphic knowledge have not advanced much on last 4 decades.

11. The calibration of the palynologycal zones is generally very low, with very few multidisciplinary studies.

REFERENCES CITED IN THE ORIGINAL WORK

Agencia Nacional de Hidrocarburos-A.N.H. (2007). Colombian Sedimentary Basins: Nomenclature, Boundaries and Petroleum Geology, a New Proposal. Edited by ANH and B&M Exploration Ltda. Bogotá.

Apache (2008). Manual de Apache http://httpd.apache.org/docs/2.2/

CakePHP (2008). Manual de CakePHP, http://book.cakephp.org/

Foote, M. (2000). Origination and extinction components of taxonomic diversity: general problems. En Erwin, D.H., and Wing, S.L., eds., Deep time: Paleobiology's perspective, v. 26: Lawrence, The Paleontological Society, pp. 74-102.

Germeraad, J. H.; Hopping, C. A. and Muller, J. (1968). Palynology of Tertiary sediments from tropical areas: Review of Palaeobotany and Palynology, v. 6, pp. 189-348.

Gradstein, Felix M.; Ogg, James G.; Smith, Alan G. (2004). A Geologic Time Scale 2004, Edited by Felix M. Gradstein and James G. Ogg and Alan G. Smith. Cambridge, UK: Cambridge University Press. 610 p.

Jaramillo, C.; Muñoz, F.; Cogollo, M. and Parra, F. (2005), Quantitative Biostratigraphy for the Paleocene of the Llanos Foothills, Colombia: Improving Palynological Resolution for Oil Exploration, in Powell, A.J., and Riding, J., eds., Recent Developments in Applied Biostratigraphy: London, The Micropaleontological Society Special Publications, p. 145-159.

Kemple, W. G.; Sadler, P. M. and Strauss, D. J. (1995). Extending graphic correlation to many dimensions: Stratigraphic correlation as constraints to optimization, pp. 65-82. Tulsa: Society for Sedimentary Geology (SEPM) Special Publication 53.

Muller, J.; Di Giacomo, E. and Van Erve, A. (1987), A palynologic zonation for the Cretaceous, Tertiary and Quaternary of Northern South America: American Association of Stratigraphic Palynologists Contribution Series, v. 19, pp. 7-76.

Open Source (2008), Definicion del concepto Open Source http://opensource.org/docs/osd