GEOLOGICAL REINTERPRETATION USING TECHNOLOGY Oil and Gas Search (OFT)

Juan Sebastian Barriera Mountain
RAMIRO ALONSO JAIMES VILLAMIZAR

UNIVERSITY OF AMERICA FOUNDATION
FACULTY OF ENGINEERING
PETROLEUM ENGINEERING PROGRAM BOGOTÁ DC 2016

GEOLOGICAL REINTERPRETATION USING TECHNOLOGY
Oil and Gas Search (OFT)

Juan Sebastian Barriera Mountain
RAMIRO ALONSO JAIMES VILLAMIZAR

Comprehensive degree project to obtain the degree of
PETROLEUM ENGINEERING

Director
HERNANDO BARRERO CHAVES
Petroleum Engineer

UNIVERSITY OF AMERICA FOUNDATION FACULTY
OF ENGINEERING PETROLEUM
ENGINEERING PROGRAM BOGOTÁ DC 2016

Acceptance note

____

____

____

Eng. Ivan Peñaloza Cristancho
Counselor

Geol. Hernan Antolinez Delgado Jurado

Geol. Andrea Pablos Juried
Runner

BOGOTA, DC - August 2016

UNIVERSITY DIRECTIVES

President of the University and Rector of the Senate

Dr. Jaime Posada Diaz

Vice-Rector for Development and Human Resources

Dr. Luis Jaime Posada Garcia-Peña

Vice-Rector for Academic Affairs and Postgraduate Studies

Dr. Ana Josefa Herrera Vargas

Secretary General

Dr. Juan Carlos Posada Garcia-Peña

Dean General of the Faculty of Engineering

Dr. Julio Cesar Fuentes Arismendi

Director (e) Petroleum Engineering Program

Dr. Edgar David Cedeño Ligarreto

DEDICATION

I dedicate this thesis, completed with great effort:

To the constant support of my parents who assisted me in any circumstance, offering me their understanding and unconditional love so as not to falter in the fulfillment of my duties as a student.

To my sister who always helped me and collaborated in all the moments in which I needed it in one way or another, and even more so the trust of my family since this process began several years ago with the participation of all of them.

To each of the professors from the Universidad de América Foundation, who provided their knowledge and emphasized the value of ethics in order to be an inclusive professional.

To my friend Professor Iván Peñaloza for giving me his guidance and confidence to achieve this goal.

To each and every one of the people with whom I had the opportunity to share my university life, who contributed to me achieving this goal that I set for myself in life.

Juan Sebastian Barrera Mountain

I dedicate this thesis, completed with great effort:

To my parents who assisted me in every circumstance, offering me their understanding and unconditional love so that I would not falter in fulfilling my duties as a student.

To my brother who always helped me and collaborated in all the moments in which I needed it in one way or another.

To each of the professors from the Universidad de América Foundation, who shared their knowledge and ethics with me in order to be an inclusive professional.

To my friend Professor Iván Peñaloza for giving me his guidance and confidence to achieve this goal.

To each and every one of the people with whom I had the opportunity to share my university life, who contributed to me achieving this goal that I set for myself in life.

Ramiro Alonso Jaimes Villamizar

ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to the following people for their collaboration and unconditional support throughout the preparation, revision and completion of this work:

To God for illuminating our paths and allowing us to successfully complete this stage of our lives.

To our families for their support, dedication and example throughout our professional training, allowing us to successfully complete our degree in Petroleum Engineering.

To the Advanced Technologies Company of Colombia SAS - CTAC, for opening its doors and hosting my degree project, providing me with technical and financial support.

To Engineer William Flórez for his help and constant support for the completion of this project.

To engineer Benjamín Garavito for his help and constant support in the completion of this project.

To Mr. Cesar Zarate for giving us the opportunity to carry out this degree project and his constant support for its completion.

To engineer Hernando Barrero for his collaboration, guidance, help and advice during the preparation of this degree project.

To engineer Guillermo Gámez for his collaboration, guidance, help and advice during the preparation of this degree project.

To Engineer Iván Peñaloza for his support and unconditional help in completing this degree project.

To Geologist Ricardo Sánchez for his collaboration, guidance, help and advice during the preparation of this degree project.

To Geologist Hoiber Patiño for his collaboration, guidance, help and advice during the preparation of this degree project.

To Mr. José Daza for his absolute support in academic counseling during the preparation of this degree project.

CONTENT

p. 29
INTRODUCTION

GOALS 30

1. GENERALITIES OF THE LA CRECIENTE BLOCK IN THE LOWER MAGDALENA VALLEY
BASIN 1.1 HISTORY 1.2 GEOGRAPHIC 31
LOCATION OF 31
THE LA CRECIENTE BLOCK 1.3 GEOLOGICAL FRAMEWORK 1.3.1 32
Stratigraphic column 1.3.2 34
Geological description of the 34
Formations 1.3.4 Petroleum geology 35
39

2. CONVENTIONAL RECORDING METHODS 2.1 SEISMIC 47
EXPLORATION RECORDING 2.1.1 Design phase 2.1.2 47
Pre-operational phase 48
2.1.3 Field operation 2.1.4 48
Topography and gauge 2.1.5 48
Generation techniques (source) 48
48
2.1.6 Types and analysis of data 2.2 52
ELECTRICAL LOGS 2.2.1 Logs to 60
determine permeable zones 2.2.2 Resistivity logs 2.2.3 61
Porosity logs 2.3 RESULTS OF 66
CONVENTIONAL METHODS 2.3.1 70
Analysis of seismic record results. 75
77
2.3.2 Analysis of electrical recording results 2.3.3 Conclusion of 82
conventional results 96

3 OIL AND GAS SEARCH TECHNOLOGY (OFT) 98
3.1 GENERALITIES 3.2 98
PHASES OF OIL AND GAS SEARCH TECHNOLOGY
(OFT) 99
3.2.1 Phase 1: Satellite Spectrography (ES) 102
3.2.2 Phase 2: Establishment of short impulse electromagnetic fields (SEMP)
106
3.2.3 Phase 3: Vertical Electroresonance Sounding (VESS) 110
3.3 DEVELOPMENT PHASES OF OIL AND GAS SEARCH TECHNOLOGY (OFT)
111
3.3.1 Phase 1 Design: Satellite Spectrography (ES) 112

3.3.2 Phase 2 Design: Establishment of short impulse electromagnetic fields (SEEF) 114
3.3.3 Phase 3 design: Vertical electro resonance sounding (VES) 117

4. IMPLEMENTATION OF OIL AND GAS SEARCH TECHNOLOGY (OFT) 121

4.1 PHASE 1: SATELLITE SPECTROGRAPHY (ES) 121
4.2 PHASE 2: ESTABLISHMENT OF SHORT IMPULSE ELECTROMAGNETIC FIELDS (ECECI) 130

4.3 PHASE 3: VERTICAL ELECTRO RESONANCE SOUNDING (SVER) 140

5. CORRELATION OF CONVENTIONAL RESULTS WITH RESPECT TO THE RESULTS OF OIL AND GAS SEARCH TECHNOLOGY (OFT) 178

5.1 STRUCTURAL MAP ANALYSIS 178
5.2 CORRELATION OF OIL AND GAS SEARCH TECHNOLOGY (OFT) ANOMALIES WITH THE STRUCTURAL MAP 185
5.2.1 Analysis 185
5.3 MODIFIED STRUCTURAL MAP 5.3.1 Map and 193
analysis 5.4 COMPARISON 193
OF STUDY TOOLS 198

6. FINANCIAL CHAPTER 6.1 201
THEORETICAL ANALYSIS OF THE IMPACT IN FINANCIAL TERMS 6.1.1 Capex 6.1.2 Opex 201
6.1.3 Income 202
6.1.4 Costs 202
6.1.5 Preparation 202
of cost tables 202
6.1.6 Why invest in oil and gas search 203
technology 205 (OFT)

7. CONCLUSIONS 207

8. RECOMMENDATIONS 208

LITERATURE 209

ANNEXES 211

LIST OF FIGURES

p.

Figure 1. La 33 **Figure 2.** Stratigraphic Column of the Lower Magdalena Valley Basin .... 35 **Figure 3.** Schematic Cross Section of the Lower Magdalena Valley .... 38 **Figure 4.** Chart of Event Times in the Lower Magdalena Valley Basin .... 41 **Figure 5.** Location of Wells in the La Block .... 43 **Figure 6.** Gas Producing Basins in Colombia .... 44 **Figure 7.** Estimated Production of the Main Gas Producing Fields in 45 **Figure 8.** Conventional Logging Methods 47
Figure 9. Seismic Exploration Development Scheme .... 48 **Figure 10.** Distribution of Seismic Line Sources and Receptors .... 50 **Figure 11.** Lateral Resolution .... 52 **Figure 12.** Two-dimensional (2D) seismic image .... 54 **Figure 13.** Advantages and disadvantages, seismic 55 **Figure 14.** Three-dimensional 56 **Figure 15.** Image interpretation results .... 58 **Figure 16.** Advantages and disadvantages, seismic 59 **Figure 17.** Types of electrical logs .... 61 **Figure 18.** Types of electrical logs .... 62 **Figure 19.** Gamma 64 **Figure 20.** Natural gamma ray spectrometry (NGS) log .... 66 **Figure 21.** log .... 67 **Figure 22.** Porosity log .... 70 **Figure 23.** Geological terrain map of 76 **Figure 24.** Location of 2D seismic lines in the La 79 **Figure 25.** Processing of a seismic analysis .... 80 **Figure 26.** 3D seismic line .... 81 **Figure 27.** Master log LCA-5 - Corpa Formation .... 84 **Figure 28.** Master log LCA-5 - Túbara Formation .... 86 **Figure 29.** Master log LCA-5 - Porquero 88 **Figure 30.** Master log LCA-5 - Porquero Medio Formation .... 90 **Figure 31.** Master log LCA-5 - Porquero 92 **Figure 32.** Master log LCA-5 - Ciénaga de 94 **Figure 33.** Master log LCA-5 – 95

Machine Translated by Google

Figure 34. Digitized structural map of the top of the Ciénaga de
Figure 35. Phases
of oil and gas technology (OFT) ....99 **Figure 36.** Oil and gas technology
(OFT) acquisition and prospecting project ....101 **Figure 37.** Spectroscopy
process ....102 **Figure 38.** Visible light
spectrum ....103 **Figure 39.** Accumulation of electrical charges
Figure 40. Wave
generator ....107 **Figure 41.** Receiving
antennas ....108 **Figure 42.** Example of an ECECI
log ....109 **Figure 43.** SVER
log ....111 **Figure 44.** Development phases of oil and
gas technology (OFT). 112
Figure 45. Satellite Spectrography
Figure 46. Satellite Spectrography Phase 1 Processing Laboratory ....114 **Figure 47.**
Short Impulse Electromagnetic Field Establishment (SPE) Phase 2 ....115 **Figure 48.**
Phase 2 Equipment Assembly and Mobilization ....116 **Figure 49.** SVER Phase
3 Vertical Electroresonance Sounding **Figure 50.**
SVER Phase 3 Field Tool Layout Process ....119 **Figure 51.** SVER Phase 3
Equipment ....119 **Figure 52.** Spectrography
Polygon #1 Location ....122 **Figure 53.** Hydrocarbon Reservoir
Type Anomaly Map ....124 **Figure 54.** Reservoir type anomaly map in
spectrographic image...............................126 **Figure 55.** Area selection for Phase 2 and
Figure 56. Gas 3-1
anomaly ....130 **Figure 57.** Location of polygons # 2
(North Area) and # 3 (South **Figure 58.** Distribution map of the ECECI study in
the North Zone ....133 **Figure 59.** Distribution map of the ECECI study in the South
Zone ....134 Figure 60. Distribution map of the ECECI in the North Zone
2.......................................136 **Figure 61.** Distribution map of the ECECI in the South Zone
2 .... 139 62. Gas 2-1 anomaly
map..142 Figure 63. SVER V01 point, Gas 2-1
anomaly...144 Figure 64. SVER V07 points, Gas **2-1**

Figure 67. SVER V10 points, Gas 2-1
anomaly..152 **Figure 68.** SVER V11 points, Gas 2-1
anomaly ....154 Figure 69. SVER V12 points, Gas 2-1
anomaly..156 Figure 70. SVER V13 points, Gas 2-1
anomaly..158 Figure 71. SVER V14 points, Gas 2-1
anomaly ....160 Figure 72. SVER V15 points, Gas 2-1 anomaly..........................

Figure 69. Vertical profile Prn2, Gas **Figure 70.** Gas
anomaly map ....152 **Figure 71.** SVER V12 points, Gas 2-2
anomaly .... **Figure 72.** SVER V14 points, Gas 2-2
anomaly ....154 **73.** SVER V16 point, Gas 2-2
anomaly ....155 Figure **74.** Vertical profile Prn3, Gas 2-2
anomaly ....156 **Figure 75.** Vertical profile Prn4 , Gas
Figure 76. Vertical profile Prn7, Gas 2-1 and Gas 2-2
anomalies ....159 **Figure 77.** Gas anomaly
map ....160 **Figure 78.** SVER V17 point, Gas 1-2
anomaly ....162 **Figure 79.** SVER point V19, Gas 1-2
anomaly ....163 **Figure 80.** Vertical profile Prn5, Gas
Figure 81. Gas 2-4 anomaly
map..165 Figure 82. SVER points V20, Gas 2-4
anomaly..166 Figure 83. Vertical profile, Gas
2-4..167 Figure 84. Oil 4-1
map .... **Figure** 85. **points** Oil
Figure 86. SVER points V04, Oil
Figure 87. SVER points V06, Oil
Figure 88. Vertical profile Prs1, Oil
Figure 89. Figure 90. Vertical profile Prs2, Oil
Figure 90. Vertical profile Prs3, Oil
Figure 91. Structural map at the top of the Ciénaga
de Oro Formation ....180 **Figure 92.** Graben -type structure 181
Figure 93. Structural map selecting the prospective zones ....182 **Figure 94.** Location of wells in the La Creciente Field on the structural map................184 **Figure 95.** Map of reservoir-type anomalies with wells drilled in the area ....
Figure 96. Map reservoir-type anomalies on a structural map in the Ciénaga de Formation .... **Figure 99.** Modified structural map ....195 **Figure 100.** Modified structural map with anomaly correlation 197

LIST OF GRAPHICS

p.

Chart 1. La Creciente Block Production 44
Chart 2. Projection of gas reserves in Colombia ....
46 **Chart 3.** Three-dimensional 57

LIST OF TABLES

p.

Table 1. Seismic recording costs 204
Table 2. recording costs 204
Table 3. costs 204
Table 4. Field work costs 204

LIST OF TABLES

p.

Table 1. Seismic line distribution methods 53

Table 2. API ranges according to rock type 64

Table 3. Rock density values 73

Table 4. Classification of anomalous zones according to the type of fluid 125

Table 5. SVER Points 141

Table 6. Fluids identified stratigraphic level 1 anomaly Gas 151

Table 7. Fluids identified stratigraphic level 2 anomalies Gas 151

Table 8. Fluids identified stratigraphic level 1 anomaly Gas 157

Table 9. Fluids identified stratigraphic level 1 anomaly Gas 167

Table 10. SVER Points Southern Zone in Oil 4-1 Anomaly 168

Table 11. Fluids identified stratigraphic level 1 anomaly Oil 174

Table 12. Fluids identified stratigraphic level 2 anomaly Oil 174

Table 13. Fluids identified stratigraphic level 1 anomaly Oil 176

Table 14. Fluids identified stratigraphic level 2 anomaly Oil 177

Table 15. Comparative table evaluating the efficiency of analysis aspects of conventional logs versus oil and gas exploration technology 198

Table 16. Reservoir Characterization 200

Table 17. Comparative table of conventional logging versus oil and gas exploration technology 206

LIST OF EQUATIONS

p.

Equation 1. Neutron Porosity .... 71 **Equation** 2.

72 **Equation 3.**

Porosity .... 74 **Equation 4.** Spectrography

Cost .... 202 **Equation 5.** Labor

Cost .... 203 **Equation 6.** Total

Costs 203

LIST OF ANNEXES

p.

Appendix A. SVER Point V01, Gas 2-1 Anomaly 212
Appendix B. SVER Point V09 , Gas 2-1 Anomaly ....
213 **Appendix C.** SVER Point V11, Gas 2-1 Anomaly ....
214 **Appendix D.** SVER Point V13, Gas 2-2 Anomaly ....
215 **Appendix E.** SVER Point V15, Gas
216 **Appendix F.** SVER Point V18, Gas
217 **Appendix G.** SVER Point V21, Gas 2-4 Anomaly ....
218 **Appendix H.** SVER Point V03, Oil
219 **Appendix I.** SVER Point V05, Oil 4-1 Anomaly ....
220 **Appendix J.** SVER Point V08, Oil 4-1 Anomaly 221

LIST OF ABBREVIATIONS

A: Ampere
ANH: National Hydrocarbons Agency
API: American Petroleum Institute
Bpd: Barrels per day
BTU: British Thermal Unit
Bwpd: barrels of water per day
CAIM-AR: high-resolution multispectral images
CAPEX: Capital costs
CCl: Gamma-Neutron
CNL: Compensated Neutron
CNT-G: Dual Porosity Neutron
ECECI: Establishment of short-pulse electromagnetic fields
EN: Satellite Spectrography
GR: Gamma Ray
Km2 : Square kilometer
LDT: Lithodensity
LDT: Spectral Density
LLD: Deep Resistivity
LLS: Shallow resistivity
LNG: Liquefied Natural Gas
mA: milli Amps
mm: millimeters
MMMPC: Billion Normal Cubic Feet
MMCF: Million Cubic Feet
MMPCD: Million cubic feet of gas per day
Mpa: Megapascals
ms: microseconds
MSFL: Microspherical focused recording
mV: millivolts
NGS: Natural Gamma Ray Spectrometry Record
OFT: Oil Finder Technology
OPEX: operating costs
PEX: Express Platform
Psi: Pounds per square inch
Rmf: Invasion fluid resistivity
Rt: True resistivity
Rxo: Resistivity of the washed zone
SAIH: Hyperspectral Image Acquisition System
SNP: Sidewall Neutron Porosity
SP: Spontaneous Potential
SVER: Vertical Electro-Resonance Sounding

Sxo: Water saturation in the Washed Zone
TOC: Total organic matter content

GLOSSARY

ABSORPTION: transfer of energy between elements, determined by the absorption of energy at the wavelengths when passing through a certain medium.

DEPOSITATION ENVIRONMENT: These are the places where sediments are preferentially deposited. Some deposition environments are located within the continents, as is the case with the fluvial environment, which is formed by the deposition of particles in the bed and on both sides of rivers, mainly during floods, or the lagoon environment, originating from the sedimented material at the bottom of lakes. Other environments are located in coastal areas and their surroundings.

AMPLITUDE: is the wave and oscillatory movement, variation of the displacement that varies over time in the path of the furthest wave point with respect to its equilibrium point.

ANOMALIES: any accumulation of material (hydrocarbons, minerals, water, etc.) in the subsoil that polarizes the adjacent rocks that surround it, which in turn alter the quasi-stationary electromagnetic fields of the Earth.

DIPOLE ANTENNA: consists of a conductor wire of half wavelength at the working frequency, cut in half, in the center of which a generator or transmission line is placed.

CLAY: Any sediment or mineral deposit which is plastic when moistened and consists of a very fine granular material, composed of very small particles less than 4 microns in size, and composed primarily of hydrated aluminum silicates.

CLAYLITE: is a compact rock, without fissility and formed by particles of the grain size corresponding to clay.

SANDSTONE: detrital sedimentary rock, formed in marine, fluvial or aeolian environments. With a clastic texture and normally fine grain, composed mainly of sand-sized minerals or rock grains and mostly composed of quartz (which gives the stone its shiny and satiny appearance). The granular sizes of its components vary between 0.02 and 4 mm.

BASEMENT: Basement typically consists of older, deformed igneous or metamorphic rocks that rarely develop the porosity and permeability necessary to act as a hydrocarbon reservoir, and below which sedimentary rocks are not common.

ECONOMIC FOUNDATION: The layer of rock below which no economic hydrocarbon reservoirs are expected to exist, sometimes referred to as the economic foundation.

LIMESTONE: Carbonate sedimentary rock containing at least 80% calcium carbonates ($CaCO_3$) or magnesium, usually calcite, consequently its CaO and CO_2 content is high. They show the same textures and structures as non-carbonate clastic sediments. They form in shallow waters and turbulent or calm conditions are reflected in the existence of grain support filled with cementing calcite or the existence of porous spaces filled with carbonate mud. It may also contain small amounts of minerals such as clay, siderite, quartz, etc.

They have little hardness and frequently contain fossils.

MAGNETIC FIELD: The magnetic field measured near the Earth's surface is the superposition of magnetic fields originating from several time-varying physical processes, which are grouped into four general components: the main magnetic field, the crustal field, the external disturbance field, and local magnetic interference. The importance of these contributions to the direction, intensity, and stability of the magnetic field varies with the geographic region and the direction of magnetic survey.

CONCORDANCE: geometric relationship between two superimposed stratigraphic units in which there is parallelism between the underlying and overlying materials.

ELECTRIC CAPACITOR: device made up of two conductive plates with equal but opposite charges. Basically, it is a device in which energy is stored in the form of an electric field. When the plates are connected to a battery, they are charged and this is proportional to the applied potential difference, the proportionality constant being the capacitance: the capacitor.

SPHERICAL CAPACITOR: An insulated metal body to which an electric potential is applied and it is charged with electrons. The electrons remain "stuck" on the surface, and the more there are per unit of surface, the greater the charge.
A spherical capacitor is simply an insulated metal sphere, which can be made of elements such as a wooden post, plastic, etc. made of any non-conductive material. A potential is applied to that sphere, or with a piece of leather or plastic, and it charges. That is a capacitor.

CONGLOMERATE: sedimentary rock composed of rounded stones, cemented in a fine matrix (sand, silt, clay), sometimes the matrix can be calcareous or siliceous and sometimes when the conglomerate has been subjected to strong pressures and temperatures the matrix can be found melted.

Conglomerates are formed in alluvial, fluvio-glacial basins, large alluvial cones (alluvial cone of the Rímac River), areas close to coastlines and on river banks.

CRETACEOUS: third oldest of the three periods into which the Mesozoic is divided. It spans approximately between 145.5 and 65 Ma before current times.

BASIN: A depression in the Earth's crust formed by plate tectonic activity and subsidence, in which sediments accumulate. Sedimentary basins may be in the form of a basin or an elongated trench.

DEFORMATION: is the effect that occurs in rocks and other solid bodies that have experienced a sufficiently high degree of applied stress. A change in shape, such as folding, faulting, fracturing, or a change, usually a reduction, in volume, are common examples of deformation observed in rocks.

DEPOSIT: Sediments that have accumulated, usually after being displaced by wind, water, or ice.

DISCORDANCE: separates two non-parallel materials from each other, which do not have temporal continuity.

DISPERSION: is the decomposition of energy into different simple sections, when a wave passes through a medium it decomposes into different wavelengths.

STRATUM: A stratum is each of the layers into which rocks can be divided due to the sedimentation process. Strata appear as horizontal layers of more or less uniform thickness, with sharp interfaces compared to the youngest stratum above and the oldest stratum below.

STRUCTURE: A geologic feature produced by deformation of the earth's crust, such as a fold or fault; a feature present in a rock, such as a fracture or a bedding surface; or, in a more general sense, the spatial arrangement of rocks.

NORMAL FAULT: is when the hanging block lowers with respect to the recumbent block of the fault. Normal faults are generally the result of tensile stresses. Synonym: Gravity fault.

FAULT: A geological fault is a fracture in the earth's crust along which rock blocks move and are separated by it. The forces terrestrial forces act on the fault zone, and therefore the rock blocks on both sides of it tend to move.

RESONANCE PHENOMENON: Every body or system has one or more characteristic frequencies, which depend greatly on the elasticity of the object or system itself or on its shape. When a system is excited to one of its characteristic frequencies, its vibration is the maximum possible. The resonance phenomenon occurs when the angular frequency of the external force coincides with the natural frequency of oscillation of the system, with an increase in amplitude.

FORAMINIFERA: small unicellular organisms belonging to the kingdom of rhizopod protists, characterized by a skeleton or shell made up of one or more interconnected chambers that fossilize relatively easily. Foraminifera are used as indicators of the depth of the water column, temperature, productivity, total ice volume, as well as geochemical characteristics of the water (pH, concentration of trace metals), and environmental pollution.

FORMATION: formal lithological unit that defines rock bodies characterized by common lithological properties (composition and structure) that differentiate them from adjacent ones. It is the main lithological division unit and its thickness must be mappable.

FREQUENCY: number of times an action is performed in a given period of time.

NATURAL SOURCES OF ELECTROMAGNETIC FIELDS: electromagnetic fields are everywhere in our environment, but they are invisible to the human eye. Electric fields are produced by the accumulation of electric charges in certain areas of the atmosphere due to storms. The Earth's magnetic field causes compass needles to point in a north-south direction, and birds and fish use it to orient themselves.

STRUCTURAL GEOLOGY: is the branch of geology that is dedicated to studying the Earth's crust, its structures and the relationship of the rocks that form them.
It studies the geometry of rocks and the position in which they appear on the surface.
UNCONFORMITY: is a surface of erosion or sediment deposition, indicated in the stratigraphic sequence by the lack of strata. In an unconformity, young deposits lie on top of older deposits without a break in continuity. There are horizontal and angular unconformities, the latter being more clearly defined for the observer.

KEROGENE: insoluble organic matter dispersed in sedimentary rocks that produces hydrocarbons when subjected to a distillation process.

LITHOLOGY: the macroscopic nature of the mineral content, granulometry, texture and color of rocks.

WAVELENGTH: A repetition interval in a wave-like disturbance. The distance between two successive crests or two successive troughs.

SHALLE: detrital sedimentary rock, composed of particles smaller than 0.06 mm in size. It consists of clay minerals (kaolinite group, montmorillonite, illite), which are formed in the sedimentary field (of neoformation) and remains of quartz, feldspar and mica. Additional components are hematite, limonite, calcite, dolomite, gypsum and sulfides.

MIGRATION: The movement of generated hydrocarbons from the source into reservoir rocks. The movement of newly generated hydrocarbons out of their source rock is primary migration, also called expulsion. The subsequent movement of hydrocarbons into the reservoir rock in a hydrocarbon trap or other accumulation zone is secondary migration.

PACKSTONE: term used by Dunham for carbonate sedimentary rocks (limestones) with a grain texture supported by a micritic matrix.

PALUDAL: accumulation of material deposited in a swamp, normally made up of silt and fine sand with abundant organic matter.

PERMEABILITY: is the capacity of the rock to allow a fluid to flow through it.

PIGGY BACK: lower block sequence, Temporal succession of thrusts in which their order of appearance is such that the new thrusts always originate in the lower or thrust block. The lower thrust sheets are more recent.

FOLD: A wavy geologic structure that forms when rocks are deformed by bending rather than breaking up under compressional stress. Anticlines are arch-shaped folds in which rock layers are convex upward. The oldest rock layers form the core of the fold, and from the core, progressively younger rocks are arranged.

POROSITY: capacity of the rock to store a fluid.

SKIN DEPTH: Skin depth, also called Skin Effect, is the increase in surface current density in the cables or power source.

generation, as the frequency increases; for example, if the frequency is low, the charge carriers use the entire cross section of the conductor, although as the frequency increases, the magnetic field increases in the central area of the conductor, making it difficult for the carriers to move to the named area, causing an increase in the current density in the surface area of the conductor.

SOURCE ROCK: A rock rich in organic matter that, if sufficiently heated, will generate oil or gas. Typical source rocks, usually shale or limestone, contain about 1% organic matter and at least 0.5% total organic carbon (TOC), although a rich source rock may contain as much as 10% organic matter.

IGNEOUS ROCK: also called magmatic, are those that have been formed by solidification of a hot and mobile rocky material called magma; this process, called crystallization, results from the cooling of the minerals and the interlacing of their particles.

METAMORPHIC ROCK: are those that are formed from other rocks through a process called metamorphism.

SEAL ROCK: is a type of rock that acts as a barrier to the escape of oil within the reservoir or field. (Generally shale).

ROCK: An aggregate of minerals or organic matter (in the case of coal, which is not composed of minerals because of its organic origin), or of volcanic glass (obsidian, which forms a rock but is not considered a mineral because of its amorphous, non-crystalline nature). Rocks may contain a single mineral, such as rock salt (halite) and certain limestones (calcite), or many minerals, as in granite (quartz, feldspar, mica, and other minerals).

SEDIMENT: is the solid material that accumulates on the Earth's surface and arises from the action of various natural phenomena that act on the atmosphere, hydrosphere and biosphere. Winds, precipitation and temperature changes are some of the factors linked to the development of sediments.

PETROLEUM SYSTEM: The geologic components and processes necessary to generate and store hydrocarbons; this includes a mature source rock, migration path, reservoir rock, trap, and seal. The correct relative chronological sequence of these elements and the processes of hydrocarbon generation, migration, and accumulation are necessary for hydrocarbon accumulation and preservation.

SPILL POINT: is the structurally lowest point in a hydrocarbon trap that can retain hydrocarbons. Once the trap has been filled to the point of spillage, its subsequent storage or retention of hydrocarbons will not occur due to lack of storage space within that trap but rather they continue to migrate until they are trapped elsewhere.

SUPLAYS: is that which lies above something. That which is located above something in particular.

STRATIGRAPHIC TRAP: A type of sealed geologic container capable of retaining hydrocarbons, formed by changes in rock type or by wedging, unconformities, or sedimentary features such as reefs. Structural traps, in contrast, consist of geologic structures in deformed strata, such as faults and folds, whose geometries permit the retention of hydrocarbons.

STRUCTURAL TRAP: A type of sealed geologic structure capable of retaining hydrocarbons, such as a fault or fold. Stratigraphic traps form where changes in rock type allow retention of hydrocarbons.

TRANSTENSION: The simultaneous occurrence of strike-slip faulting and extension, or rifting, of the Earth's crust. In transtension zones, rocks may be faulted downward to form a negative flower structure. Strike-slip faulting zones in a convergent crust undergo a transpression process, in which rocks may be faulted upward to form a positive flower structure.

WACKESTONE: geol. Carbonate rock consisting of more than 10% of grains that are within a micritic matrix, with the grains not coming into contact with each other, according to Dunham's classification (1962).

SUMMARY

This project was developed with the aim of providing a solution to the uncertainty in the identification of the reservoir limits and the possible location of development wells for the La Creciente Block area in the Lower Magdalena Valley, through the study of satellite images and the electromagnetic fields emitted by hydrocarbon reservoirs using oil and gas search technology (OFT).

The study was carried out in an area of 89 km2, in which the first phase was applied and as a result of these results, two work zones (North and South) were delimited for the application of the following two phases, which allowed the location of the best areas for future drilling and development plans.

In order to evaluate the efficiency of this new technology, a comparison was made with a structural map, which was made based on the results of conventional technologies in order to determine the location of the anomalous zones and verify the reason for the failures in some development projects, allowing to identify the advantages and disadvantages of oil and gas search technology (OFT).

KEYWORDS: Geological Model, OFT, Geological Reinterpretation, Lower Magdalena Valley Basin.

INTRODUCTION

Current levels of oil exploration in Colombia have declined considerably in recent years. Various factors have contributed to the exploration rate being one of the lowest in relation to hydrocarbon production. The latest discoveries have been smaller fields with very limited production, which does not allow for an increase in the number of proven reserves.

This is why the need to develop the following project arises, since the study of the deposit today by means of conventional methods, develops the search in the identification of geological structures suitable for the storage and production of hydrocarbons (seismic acquisition), while the technology of search for oil and gas (OFT) focuses on the identification of fluids, breaking the paradigm of conventional technologies due to its easy implementation and efficiency, allowing savings in costs and work times.

GOALS

GENERAL OBJECTIVE

To carry out the geological reinterpretation of the La Creciente Block of the Lower Magdalena Valley Basin using oil and gas exploration technology (OFT).

SPECIFIC OBJECTIVES

1. Describe the generalities of the La Creciente Block of the Lower Magdalena Valley Basin.

2. Describe the conventional methods used for locating prospective hydrocarbon zones.

3. Describe the results obtained by conventional methods in the identification of the prospective zones of the La Creciente Block of the Lower Magdalena Valley Basin.

4. Describe oil and gas exploration technology (OFT) and its operational parameters.

5. Plan the phases of development of oil and gas exploration technology (OFT) in the La Creciente Block of the Lower Magdalena Valley Basin.

6. Implement oil and gas exploration technology (OFT) in the La Creciente Block of the Lower Magdalena Valley Basin.

7. Reinterpret the geological information obtained from oil and gas exploration technology (OFT), in the La Creciente Block of the Lower Magdalena Valley Basin.

8. Compare the results obtained using oil and gas exploration technology (OFT) with conventional methods in the La Creciente Block of the Lower Magdalena Valley Basin.

9. Propose, using the results obtained with oil and gas search technology (OFT), the location of future development wells in the La Creciente Block of the Lower Magdalena Valley.

10. Compare costs by determining CAPEX (capital costs) and OPEX (operating costs) in the exploration of Hydrocarbons under the conventional method versus the costs generated by oil and gas search technology (OFT).

1. GENERALITIES OF THE LA CRECIENTE BLOCK IN THE BASIN OF THE LOWER MAGDALENA VALLEY

This chapter contains the historical overview, geographic location, geology, structural geology and petroleum geology of the La Creciente Block in the Lower Magdalena Valley Basin.

1.1 HISTORY

The La Creciente Block was discovered in 2000 and is considered one of the most promising areas for gas production with access to the sea in Colombia. It is projected to be the source of natural gas for the country and in the future to export to other regions. According to the development of the La Creciente Block, the most important discovery was reported in 2006, with part of the block called Campo La Creciente A. As time went by between 2007 and 2011, the presence of hydrocarbon resources within the La Creciente Block was confirmed, naming these new sectors Campos La Creciente D and Apamate.

Within this period of time (2007-2011), by 2008 the block's production allowed it to be marketed, since production for this period was around 35 million cubic feet of gas per day (MMPCD), as more information was obtained from the block and more wells were drilled, production the following year allowed a record to be reached that had not been reached in previous years, so in 2009 gas production was around 61.8 MMPCD.

The success of the exploratory campaigns managed to reach the production record or peak production in the La Creciente Block, with a production of 70,721 MMPCD recorded on September 8, 2011, being the highest figure reached during the history of the block.1 The commercial production of gas has continued and in recent years has been around 60 MMPCD (2013), this production supplies the thermoelectric plants of the Colombian Caribbean such as Proeléctrica (Bolívar), Gecelca (Atlántico), Termoflores (Atlántico); in the medium term, the company has established to increase the production volume in the La Creciente Block up to 100 MMPCD, with a view to carrying out projects for the export of liquefied natural gas (LNG), when it is economically viable.

This has been the greatest exploratory success in recent years, the discovery of gas fields made by Pacific Exploration & Production in the La Creciente Block, in Sucre. It was one of the first areas assigned by the National Hydrocarbons Agency (ANH) in its first year of operation. The magnitude of the discovery of these hydrocarbons is confirmed by a number of

[1] Pacific Exploration & Production, History of Pacific 2011.

certified net reserves 2P2 (calculated by adding proven reserves to probable reserves) of 420 billion normal cubic feet MMMCF (December 2012).

1.2 GEOGRAPHICAL LOCATION OF THE LA CRECIENTE BLOCK

The most important data of the Lower Magdalena Valley Basin are:

• **AREA:** 41,600 km2 . •
LOCATION: Northeast Colombia •
PRODUCTION: This basin produces an average of 458 Bpd daily, of which 70 barrels are heavy crude oil, 10 barrels are medium crude oil, and 378 barrels are light crude oil. • **OILS:** They vary from 30 ° API to 52 ° API. • **MAIN FIELDS:** Cicuco, el Difícil, and la Creciente.

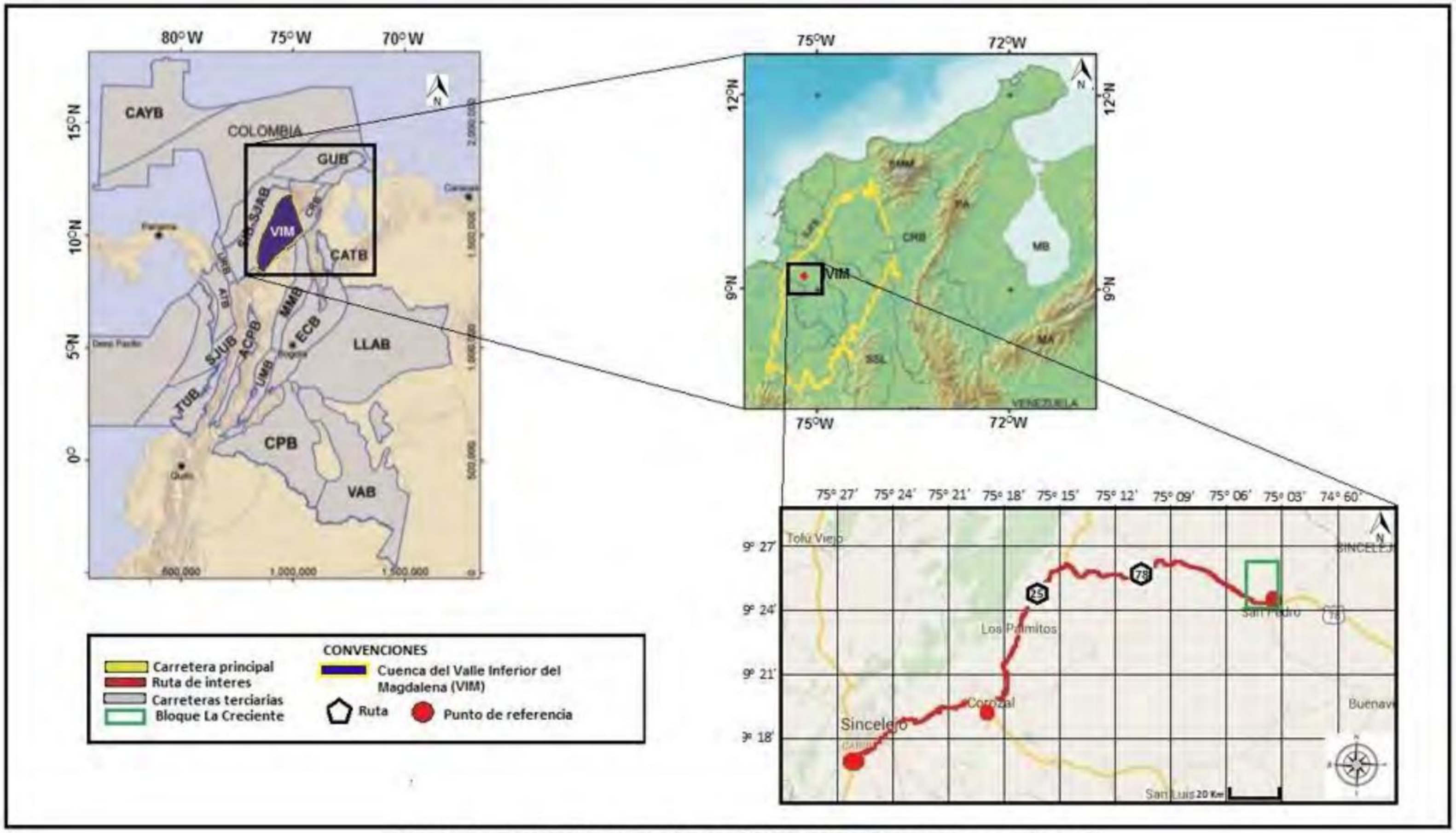
The Lower Magdalena Valley Basin is bordered to the North and West by the Romeral Fault System, to the South and Southeast by the Central Mountain Range and the pre-Cretaceous rocks of the Serranía de San Lucas and the Central Mountain Range. To the East by the Bucaramanga – Santa Marta Fault System.3

The La Creciente Block is located in the Lower Magdalena Valley Basin, within the Municipal Jurisdiction of San Pedro - Sucre, 55 km west of the City of Sincelejo. As can be seen in **Figure** 1, the location of the La Creciente Block in the department with its main access roads to the fields.

To get to the municipality of San Pedro (Sucre), the route begins as a central point in the capital city of the Department Sincelejo, taking Street 38 towards the Northeast for an approximate distance of 700 meters, then take Highway 25, within this route you will travel through the neighboring municipalities of Corozal, Los Palmitos, towards the middle of the route you will reach the surrounding area of the Municipality of El Bongo and take Highway 78 called Puerta de Hierro - San Pedro, after a journey of 55 km estimated at one hour, you will reach the Municipality of San Pedro-Sucre **(Figure** 1).

[2] National Hydrocarbons Agency, Resolution 159 of February 12, 2014, Annex 2 National
[3] Hydrocarbons Agency. Colombian Sedimentary Basins. Bogotá: ANH 2006. p.76.

Figure 1. Location of La Creciente Block



Fuente: INSTITUTO GEOGRAFICO AGUSTIN CODAZZI. Mapa geográfico del Municipio de San Pedro (Sucre). 2012. Modificado por los autores

1.3 GEOLOGICAL FRAMEWORK

The generalized stratigraphic column of the Lower Magdalena Valley Basin is presented, where the geological formations, structural geology are described and the petroleum geology of the La Creciente Field is analyzed.

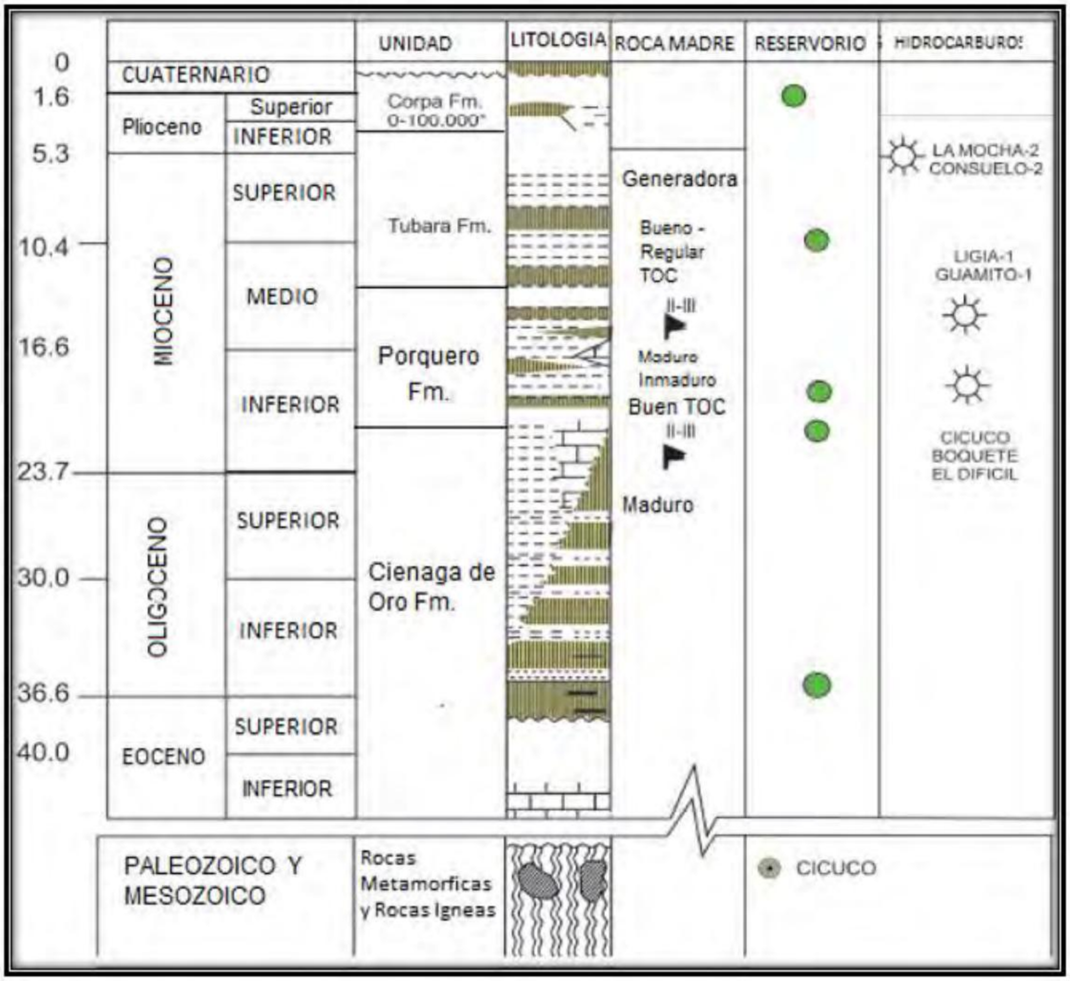
1.3.1 Stratigraphic column. The Lower Magdalena Valley is subdivided into the Plato and San Jorge sub-basins, separated by the Magangué or Cicuco Arch. The Mio-Oligocene sediments have good organic richness (TOC of 2%) and the presence of type II kerogen generating gas and liquid oil. This basin has good sandstone and carbonate reservoirs, with proven gas reserves.4

The entire deposition sequence of the strata present in the Lower Magdalena Valley Basin is presented in **Figure 2,** describing the formations present from the oldest to the youngest.

The green dots are evidence of the presence of hydrocarbons, the sun-shaped circles indicate gas wells within the basin.

[4] National Hydrocarbons Agency. Lower Magdalena Valley Basin. Volume 10. Page 44,58. 2011.

Figure 2. Stratigraphic column of the Lower Magdalena Valley Basin



Source: Stratigraphic column of the Lower Magdalena Valley taken from the book Basins of the Lower Magdalena Valley volume 10 – ANH (2011)

1.3.2 Geological description of the formations

1.3.2.1 Basement. It is composed of a complex of intrusive igneous rocks of dioritic to granodioritic composition and of low to medium grade metamorphic rocks such as green schists (chlorite-actinolite), grey to black quartzites and grey-green phyllites, or by a very weathered igneous basement washed by a meta-sedimentary sequence with electrical characteristics very similar to those of the producing areas. The age of the basement is defined as being between the Paleozoic and Mesozoic.5

[5] ECOPETROL – ICP. 2000. in Rueda et al., 2001.

1.3.2.2 Ciénaga de Oro Formation. The age of the basal part is Eocene, and the age of the upper part is Miocene. At a regional level, this formation is present in a small anticlinal structure consisting of a sequence of sandstones and mudstones. Towards the base, it is made up of a reddish oligomictic conglomerate and intercalations of carbonaceous mudstones, sandstones and coal. An average thickness of 851 feet is estimated.

As a reservoir rock, its deposition environment corresponds to a fluvial to deltaic origin, interspersed in turn with fine-grained rocks of fluvial to marine transitional origin. This formation is overlain by the Porquero Formation, the type of contact between these two Formations is of a discordant type.6

1.3.2.3 Porquero Formation. The Porquero Formation, probably defined by geologists from International Petroleum Colombia and originally referenced by BÜRGL in 1965, is lithologically defined to refer to claystones and siltstones with intercalations of fine-grained, slightly calcareous sandstones, containing foraminifera Globigerinite, dissimilis ciperoensis, which indicate an age of the Lower to Middle Miocene.

They have an average thickness of 4,935 feet. Through the study of microfauna of this unit, it has been assigned a shallow marine depositional environment. The formation is bordered at the bottom by the Ciénaga de Oro Formation and at the top by the Túbara Formation; the contacts between the two bordering Formations are of a discordant type.

The Porquero Formation is subdivided into three units, which are described below:

- **Upper Porquero Member:** It is made up of partly silt-clay with intercalations of sandstone and small packages of limestone. In the upper part, siltstone and clay predominate. Towards the middle part, intercalations of siltstone, claystone and calcareous sandstone are observed, the last two in lesser proportion; additionally, there are a few levels of limestone with very little thickness. The base is made up of light brown claystone and medium gray siltstone with little intercalation of sand, limestone and calcareous sandstone. It has an average thickness of 2,004 feet.

7

[6] Georgina Guzmán Ospitia. Geology of the Sinú, San Jacinto and Western Border Belts from the Lower Magdalena Valley, Colombian Caribbean. Page 39. July - 2004.
[7] Julivert De Porta, Union International Des Sciences Geologiques, Amerique Latine, Volume V, Fascicule 4 b, Colombia, Page 409. 1974.

• **Middle Porquero Member:** Siltstone predominates throughout the section and is interbedded with thin layers of brown claystones and quartz sandstones. It has an average thickness of 1,977 feet.[8]

• **Lower Porquero Member:** Characterized by the presence of abundant packages of claystones intercalated with abundant levels of sandstones and a small part of siltstones towards the top. At the base, the sandstone levels decrease noticeably, as does the claystone and siltstone increase and its appearance changes. It has an average thickness of 954 feet.9

1.3.2.4 Túbara Formation. The age of this formation is Early Pliocene. The lithology is composed of coarse to fine grained conglomeratic sands and light colored clays and occasional lignites. According to the samples collected and analyzed, this formation is composed of sandstones intercalated locally with yellow claystones, and towards the basal part with reddish, gray, greenish gray and light green claystones. The depositional environment of the formation is related to environments originating from a deltaic environment at the base and fluvial and lacustrine series at the top. This formation is overlain by the Corpa Formation and underlain by the Porquero Formation; the contacts between the formations are discordant. It has a thickness of approximately 1,457 feet.10

1.3.2.5 Corpa Formation. Of late Pliocene to Pleistocene age, it is made up of poorly consolidated conglomerates and alluvium, clays of different colors and scarce lignites, deposited in fluvial and deltaic environments. Locally it is characterized by the presence of packages of predominantly light yellow clays of great thickness that are occasionally interrupted by sands and sandstones towards the top of the formation and small intercalations of gypsum in the middle part. This formation is considered to have originated from a continental environment of proximal alluvial cones of fluvial currents. This formation rests on the Túbara Formation. The contact between the Corpa Formation and the Túbara Formation is of a discordant type. It has an average thickness of 4,816 feet.11

[8] Julivert De Porta, Union International Des Sciences Geologiques, Amerique Latine, Volume V, Fascicule 4 b, Colombia, Page 409. 1974. 9

Julivert De Porta, Union International Des Sciences Geologiques, Amerique Latine, Volume V, Fascicule 4 b, Colombia, Pag 409. 1974.

[10] Georgina Guzmán Ospitia, geology of the Sinú, San Jacinto and Western Border Belts from the Lower Magdalena Valley, Colombian Caribbean, Page 68, July 2004.

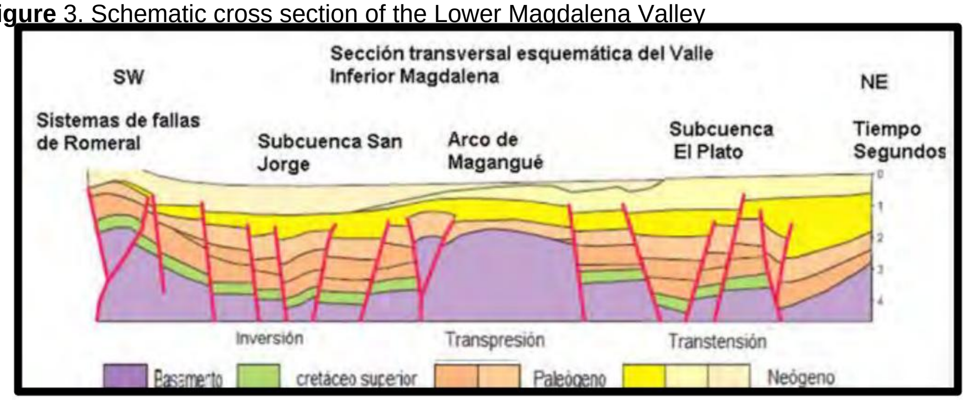
[11] Georgina Guzmán Ospitia, Geology of the Sinú, San Jacinto Belts and the Western Edge of the Lower Magdalena Valley, Colombian Caribbean, July 2004, p. 96.

1.3.3 Structural geology. The Lower Magdalena Valley Basin is a triangular transtensional basin limited to the north-west by the Romeral Fault System and to the south-southeast by the metamorphic rocks and igneous complexes of the Central Mountain Range and the San Lucas Mountain Range.12 The eastern limit of the basin is the northern part of the Santa Marta-Bucaramanga Fault System. A basement high divides the basin into the El Plato and San Jorge Sub-basins. See **Figure** 3.

The continental margin of the Colombian Caribbean is part of the deformation front originated by the subduction of the Caribbean Plate under the South American Plate. The tectonic characteristics, dominated by the interaction of these plates, determine the structural and stratigraphic patterns that are present in the geological provinces of northern Colombia.

The evolution of northern Colombia results in blocks that are presented as tectonic and stratigraphically differentiated regions.

Figure 3. Schematic cross section of the Lower Magdalena Valley



Source: Modified by the authors, taken from Colombian sedimentary basins (ANH) year 2009. Modified by the authors.

The Lower Magdalena Valley is defined as a positive zone prior to the Late Cretaceous (continental crust), whose tectonic activity begins with the collision of the Caribbean plate with the South American Plate. It is currently divided into two (2) main depocenters known as the El Plato Sub-basin to the North and the San Jorge Sub-basin to the South, divided by a basement high called the Magangué Arch or Cicuco Arch with a Northwest-Southeast orientation.13

The tectonostratigraphic events of the Lower Magdalena Valley can be summarized within the following series of pulses during deformation:

[12] National Hydrocarbons Agency, Colombian Sedimentary Basins. Bogotá: ANH 2006. p.44.
[13] PETROSEIS LTDA. Final seismic interpretation report, p.13. 2011.

- **Conacian – Paleocene:** Deformation associated with the oblique collision of the continental arc, propagating from south to north, developing the Romeral Fault System, which separates the continental and oceanic domains, accretion of oceanic crust to the west of the suture, and the sedimentation of deep waters to the west of the boundary, leaving the Lower Magdalena Valley without deposits.[14]

- **Eocene – Oligocene:** The Lower Magdalena Valley Basin is activated, accretion of the San Jacinto Fold Belt, collapse of a region of the Central Mountain Range of the San Jorge Plate Sub-basin, mostly turbidite deposition.[15]

- **Miocene:** "Piggy back" basins filled with sediments from a regressive event. East of the Romeral Fault System, a NS compression involving basement and an inversion of existing structures developed (Flinch, 2003). The collision of the Panama Arc is the cause of the deformation of the Central Cordillera.[16]

- **Pliocene:** Depocenters migrate offshore from the Miocene and an inversion of the Plate-San Jorge Subbasins occurs and the final pulse of Andean orogeny is recorded. The strong regression is mainly responsible for the rapid changes from marine, coastal to continental facies.[17]

1.3.4 Petroleum geology. The petroleum geology for the Lower Magdalena Valley Basin is described below.

1.3.4.1 Source Rock. The Ciénaga de Oro and Porquero Formations, deposited at the end of the Oligocene and beginning of the Miocene, are recognized as stratigraphic units with source rock potential. These formations present intercalations of shales of fluvial to marine transitional origin.

The Porquero Formation is considered the source rock of the Lower Magdalena Valley, due to the oil and gas generating kerogen, which has a total organic content of 2%. After 8,200 feet the sequence presents type III kerogen, this interval could be considered as deposited during a maximum flood event.[18]

1.3.4.2 Reservoir Rock. The Ciénaga de Oro Formation, in some segments, is composed mainly of laminated lithic arenites (parallel plane lamination, wavy, flaser, wavy and lenticular), lithic arenites and quartz arenites.

[14] Ibid, p.13. 2011.
[15] Ibid, p.13. 2011.
[16] Ibid, p.13. 2011.
[17] Ibid, p.13. 2011.
[18] National Hydrocarbons Agency, Colombian Sedimentary Basins. Bogotá: ANH 2006. p.76.

massive to very fine-grained to fine-grained bioturbated, and decreasing grain-width sequences of very coarse- to medium-grained lithic arenites, locally conglomeratic.
Abundant fossil remains, glauconitized fecal pellets, muscovite and carbonaceous sheets and fragments and subordinately there are medium to very thick layers, sometimes in decreasing grain size sequences, of wackestones and packstones, massive bioclastics, and massive, polymictic matrix-supported conglomerates, with subrounded to subangular clasts, mainly of quartz (up to 90%), chert, and fragments of sedimentary rocks. It has an average porosity of 15%.19

1.3.4.3 Seal Rock. Some shales present in the upper part of the Porquero and Ciénaga de Oro Formations are considered seal units because they have excellent characteristics for this function.

1.3.4.4 Migration. The field is considered to be composed of a system of fractures and fault planes which become the probable migration routes. First, the fluids migrate through the intercalations of sandstones, limestones and shales that make up the Ciénaga de Oro Formation, another mode of migration is the displacement of the fluids laterally within the same formation, subsequently contacting the fractures and fault planes present in the formation to finally migrate.20

1.3.4.2 Traps. The structures related to anticlinal folds are generated by transpression effects, they play an excellent role as traps in the field, as do the various structural traps and mixed traps present in the field, the above are important structural exploration objectives in the field.21

1.3.4.1 Timing and event chart. Figure 4 illustrates the times of the events in which the deposition of the source, reservoir, seal and overburden rocks occurred, the time of trap formation, as well as the interval in which the migration and accumulation processes occurred. The preservation interval and the critical moment are also shown.

The sedimentary sequence of the study area was deposited in relatively shallow marine paleoenvironments (on average with bathymetries less than 164 feet), subject to variations in the water column, with high primary organic productivity and with sedimentation dominance in the littoral zone with continental influence; it is interpreted that the accumulation of these rocks took place between the

19Ibid, p.78.
[20] National Hydrocarbons Agency, Lower Magdalena Valley Basin. Colombia Oil and Gas. 2007.

21 Ibid. 2007.

platform and lower beach front for the Porquero Formation (Tertiary-Miocene) and in deltaic to shallow marine environments, for the Ciénaga de Oro Formation (Tertiary-Oligocene).

For the Tertiary-Miocene Túbara Formation, depositional paleoenvironments are interpreted as being associated with alluvial/deltaic plains at the base, followed by lagoonal and/or coastal swamp sedimentation, and the upper layer as the transition between foreshore/bay environments and upper beachfront.

After the sedimentary processes associated with the respective lithification and diagenesis, it can be determined that from the interaction of the South American and Caribbean plates, three periods of tectonostratigraphic evolution have been identified. The first one runs from the Oligocene to the Early Miocene (1, in Figure 4), characterized by large tilted blocks limited by high-slope normal faults. The second period, Early Miocene to Late Miocene (2, in Figure 4), characterized by high subsidence as a result of isostatic accommodation in response to the first pulses of the Andean Orogeny and the third period corresponds to the Andean orogenic pulse as such (3, in Figure 4). The critical moment occurs around 2 million years in the Early Pleistocene, as observed in Figure **4 .**

Figure 4. Chart of event times in the Lower Magdalena Valley Basin

Source: Modified by the authors. Chart of events taken from the book Cuencas del Valle Inferior del Magdalena volume 10 – ANH (2011)

1.3.4.2 Production history. The development of the La Creciente Block has been marked by the constant exploratory campaigns carried out in this area.
It all goes back to August 19, 2004 when the Exploration and Exploitation Contract for the La Creciente Block was signed, this was awarded by the

National Hydrocarbons Agency to the operator Pacific Rubiales Energy, with an initial area of 39,367 hectares with 4,536 square meters.

Years later, on September 13, 2006, Pacific Rubiales Energy Company began drilling the La Creciente 1 Well (LCA-1), and conducted prospecting studies and 2D and 3D seismic acquisition to identify future drilling locations. The La Creciente Block is divided into 3 main fields, which are La Creciente A, La Creciente D and Apamate.

On December 19, 2007, the studies allowed for a production of 68,960 MMPCD of gas, 34,758 barrels of condensate per day (Bpd) and 60,760 barrels of water per day (Bwpd) for the La Creciente A Field, as well as for the La Creciente D Field a production of 2,832 MMPCD, 536 Bpd and 79,055 Bwpd.

with cut-off date of December 31, 2011.[22]

In the La Creciente A field, a series of wells have been drilled which support the production of the block. The production is divided into the La Creciente 1, La Creciente 2, La Creciente 3 and La Creciente 4 wells. Unlike the La Creciente D sector, its production is supported by the La Creciente D-1 well. These 5 wells are capable of producing higher quantities, but due to the conditions of the production facilities of the Block, some wells had to be closed for a certain period of time.

The Apamate 1 Well, located in the La Creciente Block, began production in May 2011 and has a production of 1,215 MMPCD, 826 Bpd and 12,655 Bpdw at the end of 2011.

Pacific Exploration & Production has been concentrating its development in the La Creciente Block with the Apamate-1X Well, where the producing zone is considered to be the Ciénaga de Oro Formation with an interval between 11,139 to 11,180 feet and a drainage area of 307 acres. This project is of great interest because the original gas in place is 14,303 MMCF with a recovery factor of 0.75 where the recoverable gas is estimated to be 10,727 MMCF.[23]

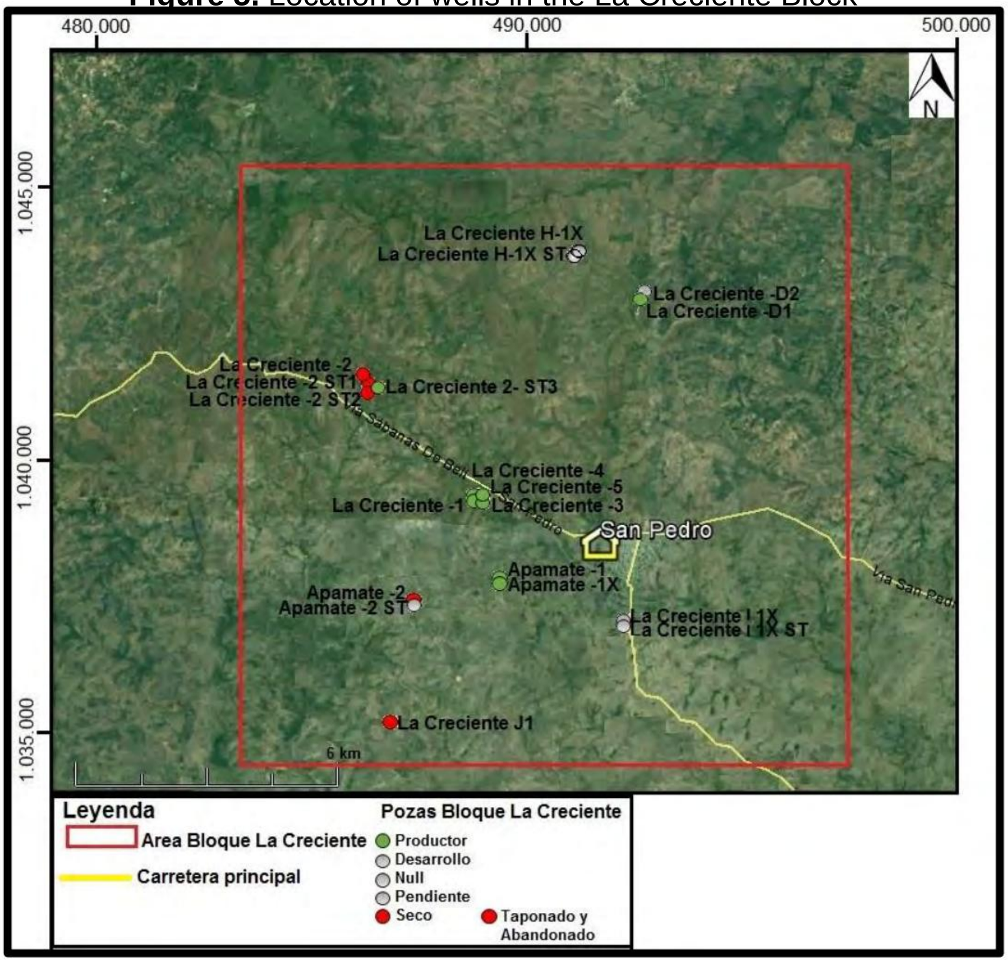
As a summary of the production of the La Creciente Block, the results of the most important wells and their respective location are shown as shown in the
Figure 5:

• Apamate-1 well: dry gas production. • Apamate-1X well:
dry gas production. • Apamate-2 well: plugged and abandoned.

[22] PACIFIC EXPLORATION & PRODUCTION, History of Pacific 2011.
[23] PACIFIC EXPLORATION & PRODUCTION, History of Pacific 2011.

• La Creciente 1 well: dry gas production. • La Creciente 2 well: plugged and abandoned. • La Creciente 2.ST1, ST2 well: plugged and abandoned. • La Creciente 2.ST3 well: dry gas production. • La Creciente 3 well: dry gas production.
• La Creciente 4 well: dry gas production. • La Creciente 5 well: dry gas production. • La Creciente D1 well: dry gas production. • La Creciente J1 well: plugged and abandoned.

Figure 5. Location of wells in the La Creciente Block



The La Creciente Block is considered one of the most important gas producing fields in Colombia. As can be seen in Figure **6 ,** the Lower Magdalena Valley Basin is classified as one of the most important areas with the presence of gaseous hydrocarbons. More than 273 wells have been drilled in this basin that support gas production.

Likewise, this Basin has condensate production as is explicitly stated in column three **(Figure** 6) of total production in 2010. Of the total seismic (2D) carried out in the Lower Magdalena Valley Basin, more than 50% corresponds to the area of the La Creciente Block with its various production fields.

Figure 6. Gas producing basins in Colombia

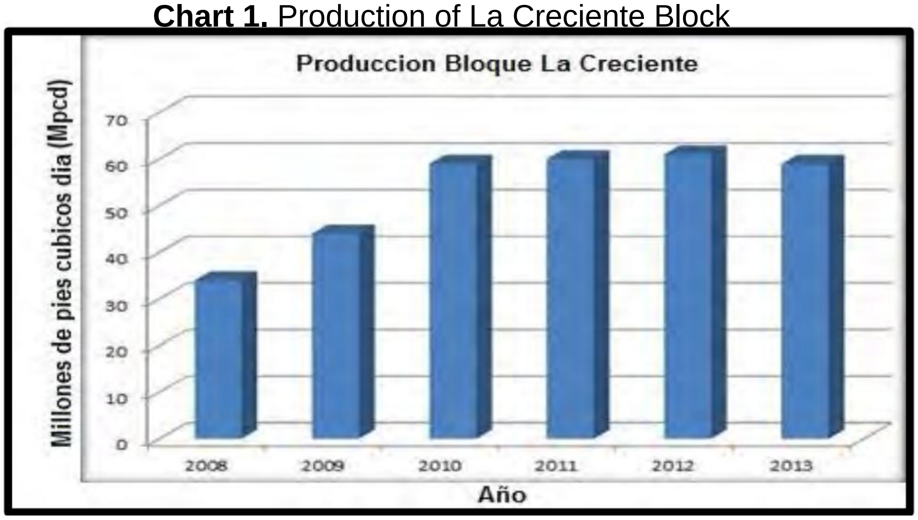
Cuencas Emergentes

Cuenca	Area cuenca (Km²)	Producción Total 2010	No. Campos	Número de pozos	Sísmica 2D (Km)
Guajira y Guajira offshore	66,639	248,0 GCFG	2 gas	78	24,074
Cesar-Ranchería	11,668	ND	2 oil + 3 gas (NCP)	67	3,458
Sinú-San Jacinto	69,221	ND	3 gas	205	26,343
Valle Inferior del Magdalena	**38,017**	**23,4 GCFG + 178,682 B O**	**4 oil + 5 gas**	**273**	**16,704**

Source: General information Sedimentary Basins of Colombia – ANH (2002)

According to a 2014 Colombian oil and gas information system supply report, **Chart 1** represents the daily production of the La Creciente Block within the first 6 years of production, with peak gas production since 2010 in the order of 60 million cubic feet per day.

Chart 1. Production of La Creciente Block



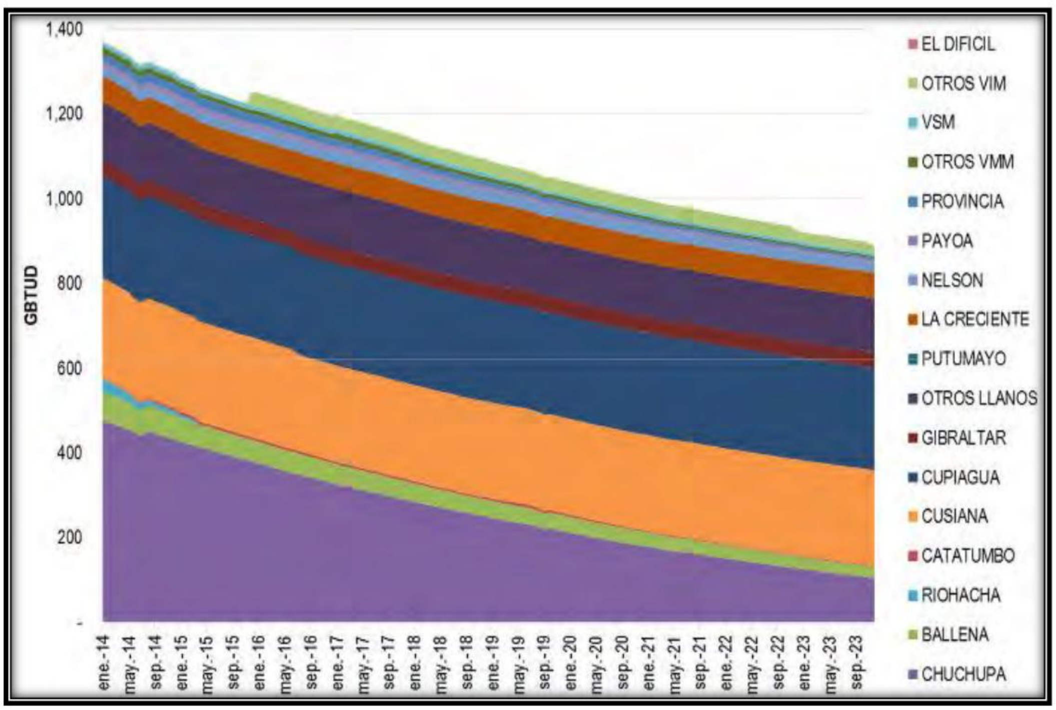
Source: Modified by the authors with data based on the report of the Mining and Energy Planning Unit – Natural gas balance 2014-2023

Based on production, the Colombian Mining and Energy Planning Unit made an estimate of the production rate evaluated from January 2014 to September 2023, taking the highest production data from 2014, which was 1,360 Giga BTU per day, and interpolating from there to be able to set a maximum production goal reflected until 2023, which is shown below in **Figure 7.**

Within this, **Figure 7** shows the gas production of the different fields existing in the Colombian territory, highlighting with greater production the fields Chuchupa (Guajira), Cusiana (Casanare), Cupiagua (Casanare), other Llanos (Meta-Arauca) and in fifth place is La Creciente (Sucre).

Considering that the first four fields are mature fields with more than 25 years of production, the opposite is true for La Creciente Field, this field was discovered between 2006 and 2007, having a development time of 10 years, occupying an important place in the country's gas production.

Figure 7. Estimated production of the main gas producing fields in Colombia



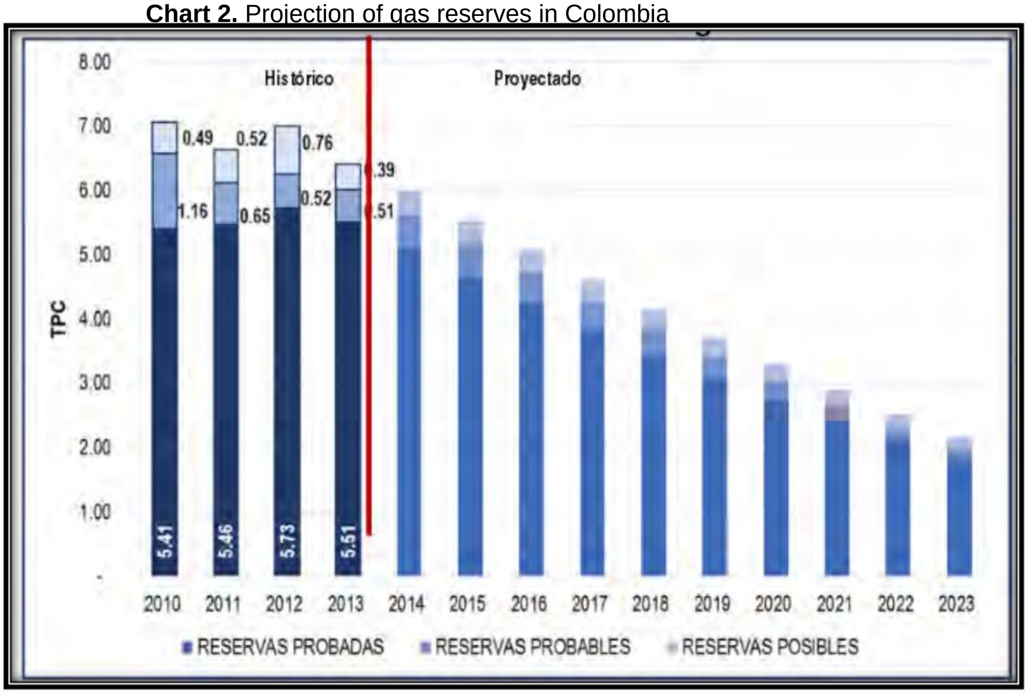
Source: Report of the Mining and Energy Planning Unit – natural gas balance 2014-2023. 2014.

The fields that contribute to the gas production of the Lower Magdalena Valley are Arianna, Cañaflecha, Nelson, La Creciente A, La Creciente-D, Bonga, Mamey, Brillante, El Difícil. It can be defined that the proven reserves have already decreased.

There have been no significant new discoveries, which is why we must invest in exploration to increase our reserves.

Chart **2** represents the projection to 2023 of how the relationship between proven, probable and possible reserves will be, with the highest point of this relationship in 2013. As time goes by, this relationship will decrease as demand increases in the country and therefore, by 2023, the order of reserves will be at 2.00 Tera Cubic Feet. This is why it is important that exploration in the fields continues at the rate of the years 2010 to 2012.

Chart 2. Projection of gas reserves in Colombia



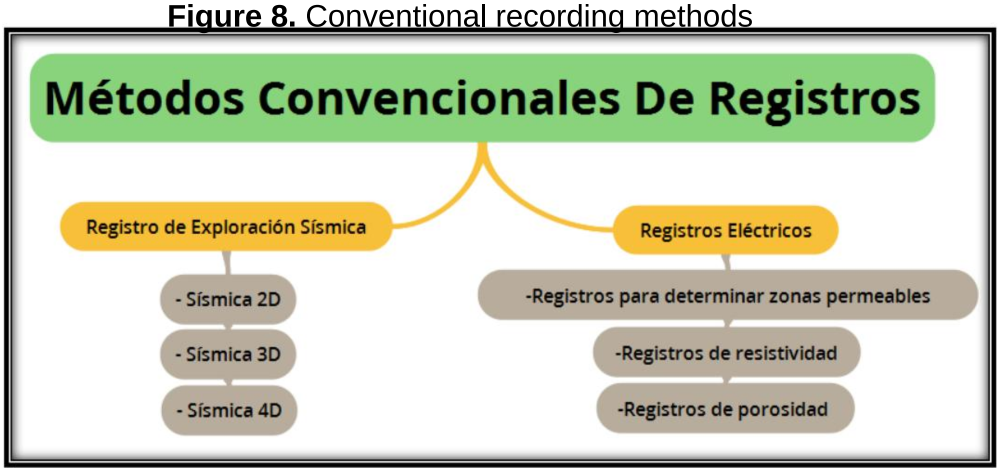
Source: Mining and energy planning unit report – natural gas balance 2014-2023. 2014.

2. CONVENTIONAL RECORDING METHODS

This chapter develops the study of conventional methods of logging in the search for hydrocarbons. A detailed description of seismic exploration and electrical logging carried out in exploration areas and wells will be found. It also covers the aspects that must be taken into account when taking any necessary data, the advantages of these acquisition methods and, in turn, the shortcomings of each method when carrying out an analysis and interpretation of possible hydrocarbon accumulations.

Figure **8** defines the types of records to be explained in this chapter:

Figure 8. Conventional recording methods



2.1 SEISMIC EXPLORATION RECORD

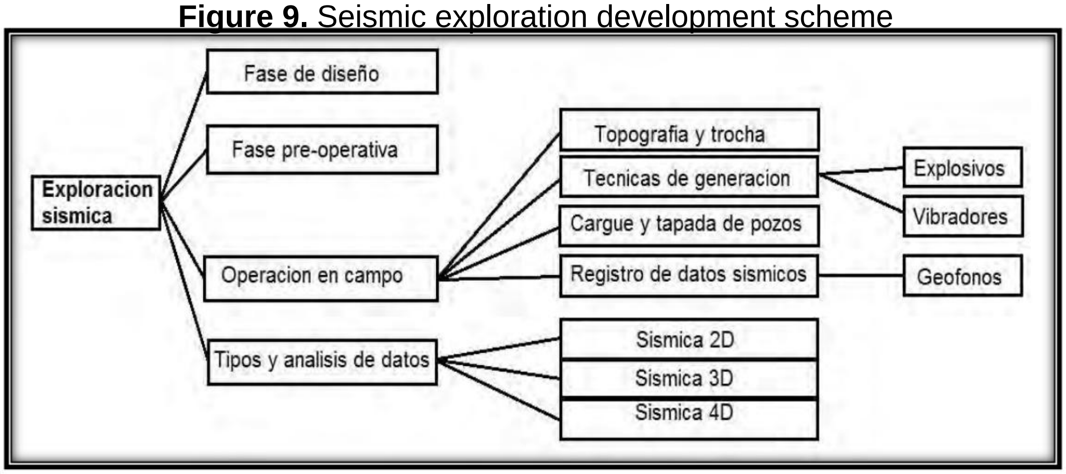
Over the years, the oil and gas industry has had a number of sources of information and data acquisition in hydrocarbon exploration. These sources have allowed to determine over time the areas with the characteristics suitable for the storage and production of hydrocarbons. The means used for the identification of the different accumulations of hydrocarbons in the world are mechanisms linked to and based on the development of the study of the earth through scientific research.

Seismic data acquisition and processing is the most widely used method in the oil and gas industry, mainly used to identify traps and characterize reservoirs, among others. This is the main exploration tool, through which an image of the subsoil is obtained, showing areas where possible accumulations of hydrocarbons may exist.

The technique used in seismic exploration consists of the artificial generation of acoustic waves, which travel through the layers of the subsoil and are reflected towards the surface in response to the impulse in the passage of each layer. The return of these waves is captured and recorded by detectors called geophones in order to form the seismic image of the area, remembering that seismic exploration is a technique with low environmental impact, respecting environmental requirements and the value of the natural resource.24

The development of seismic exploration will be linked to the procedure illustrated in **Figure** 9.

Figure 9. Seismic exploration development scheme



2.1.1 Design phase: In the early stages, seismic exploration is based on the collection of information from the region, generating a model that takes into account factors such as: workplace, social responsibility, communities, properties, etc.

2.1.2 Pre-operational phase: in the second phase, environmental and social management is determined, such as relations with the authority, agreement between the parties, agreement on the project in the area of influence, staff training, adaptation of locations and negotiation of land.

2.1.3 Field operation: following the seismic exploration scheme, the field operation phase includes stages such as: **2.1.4**
Topography and trail: adaptation of the road, defining the location of receiving stations and source points, allowing topographic leveling, personnel access, among others.

2.1.5 Generation techniques (source): they are carried out by means of systems that transmit energy to the subsoil represented in waves or vibrations, these

24 Pacific Rubiales Energy, Geophysical Operations, Vice Presidency of Exploration. Seismic Exploration. 2014.

The generated waves advance along the subsoil, crossing the arrangements of lithological units or Formations (layers of the earth), these units are
The seismic lines are characterized by physical-chemical properties that generate a disturbance as the wave passes through, reflecting the change in the speed and propagation of the wave. The contrast presented in the seismic lines coming from the bottom will be determined by the lateral variation according to the material that it passes through, for this reason the resolution in the seismic method is important since defining the minimum vertical distance between two interfaces is necessary for a single reflection to occur.25 Regarding the generation of the disturbance, this is generated from artificial sources (seismic gel, hammer, vibro), which in turn propagate in the subsoil. The quantity of waves necessary to generate the reflection in the different strata, thanks to the reaction of the medium to the disturbance. Data on amplitude, wavelength, phases and double times of the subsoil reflectors can be determined, this limited by the elasticity of the layer, at the moment in which the wave returns to the surface it is captured by instruments that receive
This information (geophones) can then be modelled in the various computer programmes available in the industry.

- **Explosives:** It begins with the drilling of wells at shallow source points. To carry out this work, a group (crew) is needed in the study area to adapt hydraulic equipment, mechanical towers and portable drills. This equipment can work with water, air or punches and its use is decided according to the topography and geology of the work area.

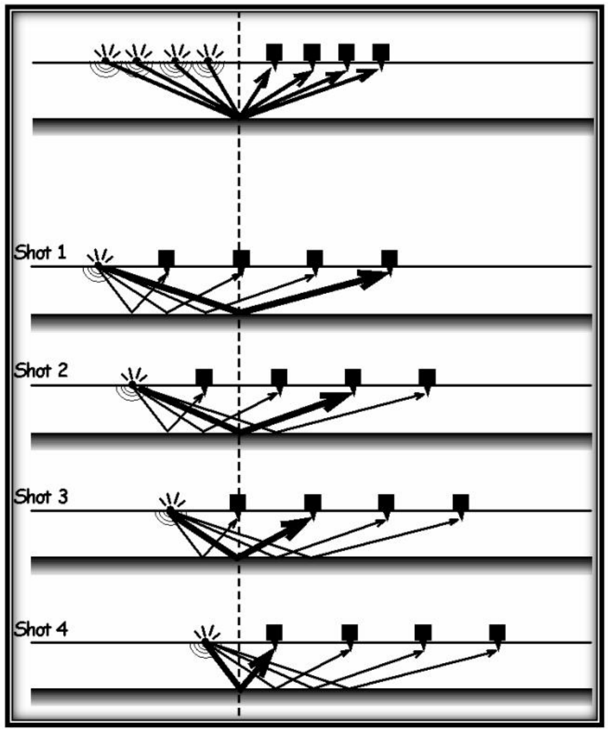
The perforations are established according to the lines that the client has decided to survey (distance between wells of 5 to 60 meters on average), the diameter of the perforations is in the order of around 2 to 3 inches, the depth of the perforation is established in the design of the project (2 to 20 meters on average), as the perforations are carried out on the study lines, in each perforation the seismic gel is deposited, this element is a dense explosive with the capacity to be submerged in water, with high detonation speed, which generates a strong and sharp energy necessary for the study of seismic surveys at the time of the explosion.

For **Figure 10,** an example of a source and receiver distribution is shown, in the first section a 4:4 arrangement is observed, with the reflected energy being recorded by four groups of receivers. To collect seismic profiles, there are different arrangement distributions for both sources and receivers. Inspection of Figure **10** shows four shot (source)-receiver combinations with a common midpoint (CMP) configuration in the subsurface. During processing, the seismic processors through

[25] Herrera Yajaira, Manual for the acquisition and processing of terrestrial seismic and its application in Colombia. National University. 2010.

All combinations of sources and receivers find a common middle ground.

Figure 10. Distribution of sources and receivers seismic line



Source: Principles of 2D and 3D Seismic Interpretation.
Chapter 1, Lateral Resolution, 2004.
Modified by the authors.

- **Vibrators:** This energy source is a mechanical source, the device is mounted on a truck, which through vibration generates seismic energy waves from the surface, generally this source is used when it is not possible to use explosive sources. The generation of vibrations can be run in different directions, one of them is the sweep of high frequencies to low frequencies (downward sweep), or on the contrary from low revolutions to high revolutions (upward sweep).

An advantage of this source is that more than one vibrator can be used in order to improve the quality of the data obtained and to cover a larger area of land (desert areas).

As the distance between the source and the receiver increases, the wave train becomes longer and the waves that have traveled mostly as primary waves arrive much earlier than those that propagate as secondary waves. Surface waves are also mainly sensitive to the velocity secondary structure that propagates back from the most distant depth environments.

Once the wave train begins to resemble a sequence of isolated phases it becomes the task of developing approximate design techniques to synthesize a particular phase. However, in order for these approximations to be made efficiently it is necessary to understand the nature of the propagation process.

- **Loading and capping of wells:** once the well is opened, the previously mentioned energy source material (Sismigel) is introduced, the wells are capped up to the surface with the drilling material, fixing the geophones in the same period and connecting them through cables that record and transmit the information of the waves emitted by the energy sources.

2.1.5.1 Seismic data recording (receivers)

- **Geophones:** This instrument detects the speed of the wave produced in the ground, interpreting the seismic wave in the movement of electrical impulses.

  These detect movement in one direction, for the different seismic acquisition arrangements this instrument is placed in a linear manner to the sources or varies in geometric arrangements such as the orthogonal arrangement in the acquisition of 3D seismic data, the signals produced are converted to a final element such as geological information of the different layers present in the subsoil.

The general feature of geophone placement in an array is that it rarely extends more than 5 km from the source. Many receivers are used for each source, thus allowing only the source point to be moved and the recording to be repeated. The multiplicity of elements on the surface increases the coverage so more ground can be exploited to enhance any weak depth reflections that exist.

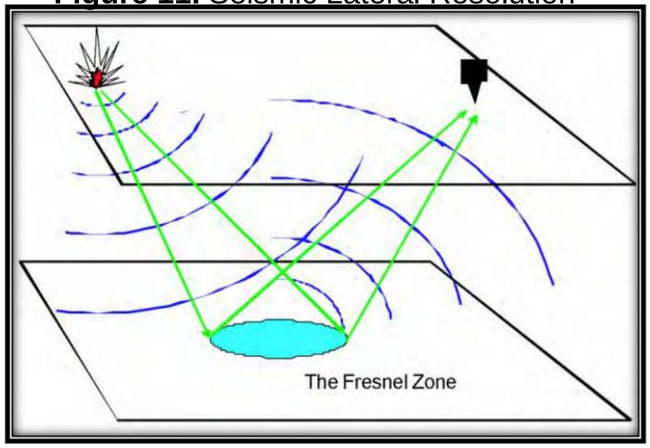
Among the most used Geophones are:

ÿ Electromagnetic geophone ÿ
Reluctance geophone ÿ
Capacitance geophone ÿ
Piezoelectric geophone

The seismic data obtained should not be interpreted independently. Both the geological and geophysical parts generate experience in the analysis and interpretation, and therefore the data must be included in a complete interpretation.

Figure **11** shows the conventional source-receiver arrangement scheme, in which for each source there is a receiver arranged for receiving the information, the lateral resolution in the study areas of seismic data images, in which it illuminates the area of interest at a certain point, is subject to the average speed up to the horizon of interest, two travel time paths, one the generating area (source), and the receiving area (geophones).

Figure 11. Seismic Lateral Resolution



Source: Principles of 2D and 3D seismic interpretation. Chapter 1, Lateral resolution, 2004. Modified by the authors.

2.1.6 Data types and analysis. Once the seismic signal is obtained, the final process of modeling the data into suitable structures represented in the image is entered, but before this, the types of data that exist are based on the scientific principle of geophysics, depending on the environment in which it is acquired (marine, terrestrial and transitional). The scientific principle of seismic study is the measurement of the speed of propagation of waves in the subsoil (wavelength (ÿ), meters/feet), by measuring time and intensity of the reflected wave you can know the depth and thickness of the layers in the subsoil (amplitude, positive (peaks) - negative (channels)), this is a technique that allows the interpretation of data information of the subsoil, and the clarity of the data is subject to the resolution of the information reflected in the layers, among the parameters established to identify what material lies in the subsoil the duration of the time line (frequency (f), cycle/sec- Hz) gives the approximations of the waves generated on the surface and which in turn are reflected in the strata of the earth.

In seismic acquisition surveys, the information provided by data storage equipment can be modeled in three existing processes, these information presentation models are called 2D, 3D and 4D seismic data acquisition.

2.1.6.1 2D seismic. Two-dimensional reflection seismic, in this type of profile, after obtaining the information from the vehicle and recording instruments (geophones), the profile shows a cross section of the study area, added to the information from existing wells, a map is created with the different lithologies existing in the subsoil. The 2D lines have a number of receiver and source units, which by varying each of these allows modeling and obtaining geological information.

This data acquisition is carried out to provide support for three-dimensional (3D) seismic surveys. In addition, this technique is able to cover larger areas of land, generating the conformation of the terrain on a plane, and of course, this is the most economical of the existing methods.

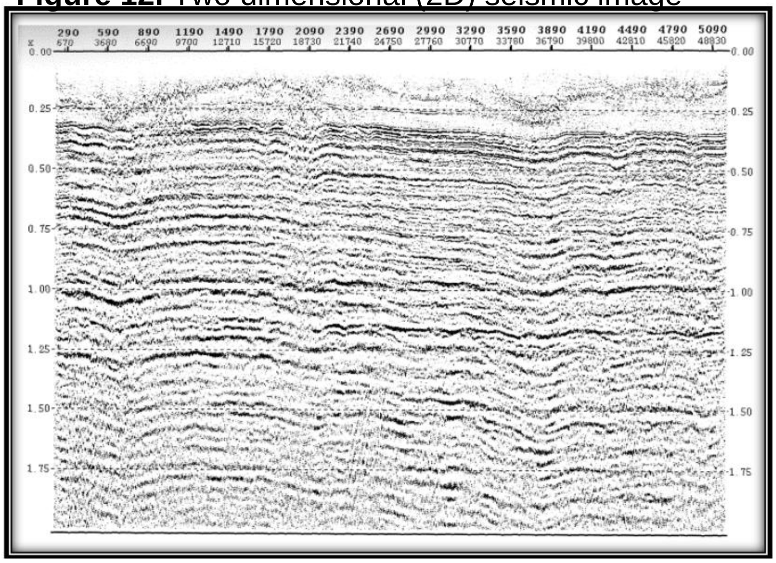
Two-dimensional (2D) seismic data acquisition is the simplest form of a type of survey, but depending on the method used (distribution of generators and receivers), it affects the acquisition of data. The most important distributions of two-dimensional (2D) seismic data acquisition are listed in **Table** 1, referring to seismic line distribution methods. It is important to mention that a 2D line covers a very limited coverage, in terms of the distance from the source and the receiver, called the margin effect.

Table 1. Seismic line distribution methods

Wide strip method	**Propagation method**
Various receiving lines are projected at a certain distance from the source, but with the advantage of generating a vertical sweep like the margin effect at a greater distance between each generation line, obtaining a larger studied area of the area of interest.	The location between sources and receivers is done with a trajectory opposite to each one, this method is not widely used in areas with the presence of water sources.

Once the information is obtained, a series of seismic images are established that are subject to classification and determination of the geological information present. Figure **12** shows a 2D acquisition ready for the static corrections to be applied. This Figure presents data to be interpreted and generate the previous reading of the image.

Figure 12. Two-dimensional (2D) seismic image

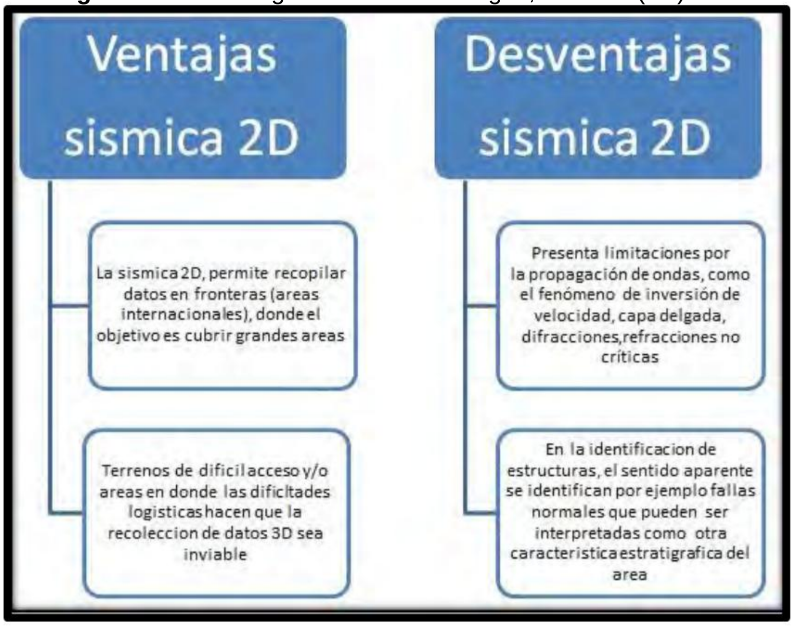


Source: Principles of 2D and 3D seismic interpretation. Chapter 2, Seismic information analysis, 2004. Modified by the authors.

The data recorded in the field are interpreted and based on this a two-dimensional (2D) data model image is generated, from then on with the other existing interpretations; in the process the artifacts associated with the way in which the data was acquired, noise and trajectories of the waves generated are eliminated, since acoustics is the energy on its way from the source to the receiver that will be altered. These manipulations are known as seismic data processing, the processing is a mixture of art and science, it focuses on 2D seismic acquisition and processing because the concepts are easier to introduce, in this type of data.

The advantages and disadvantages of the two-dimensional (2D) seismic data acquisition method, corresponding to **Figure 13,** are shown below .

Figure 13. Advantages and disadvantages, Seismic (2D)

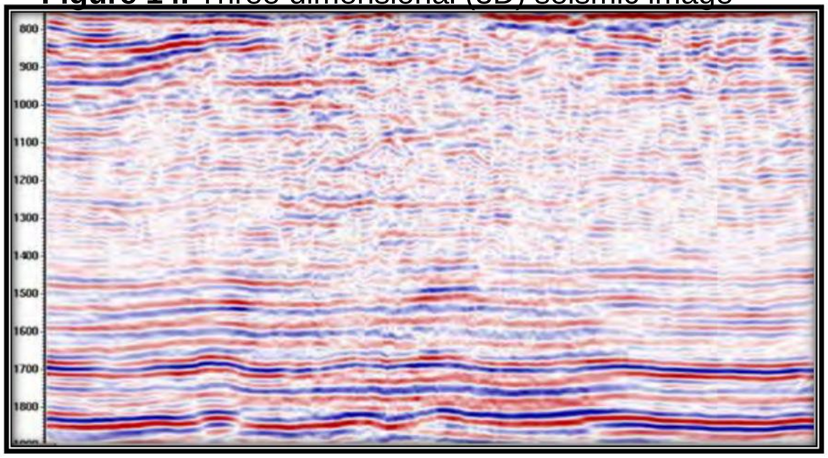


2.1.6.2 3D seismic. Three-dimensional seismic surveys are determined by the shape and arrangement of the different lithological units. This geophysical method, like the 2D model, allows images to be obtained, but in this case a three-dimensional image is obtained. The data obtained are modeled in a computer process consisting of mathematical processes, thus constructing the geological model of the layers of the Earth's crust. The model obtained is presented in horizontal or vertical sections, or a combination thereof. This model has the advantage of improving the signal-to-noise ratio of the waves and their continuity in the medium. Another advantage of this model is the large amount of information it provides. **2.1.6.3** 3D seismic data provide a volume that allows structures to be defined more precisely. The information that can be obtained is a clearer image of the subsoil, with the structure and properties of the rock. Interpretations based on 2D seismic or log data routinely exhibit higher degrees of uncertainty than those obtained with 3D. 3D seismic acquisition focuses on enhanced imaging migration of the subsurface. Most seismic data used in the petroleum industry are collected via the common midpoint method.

The form of these arrangements are generally orthogonal arrangements, accompanied by various work configurations, all subject to the design and acquisition parameters determined by the companies, in the survey area, variables such as data quality, the environment, the possible production of the area and the project budget.

Figure **14** shows cross sections at different depths, for acquisition in 3D seismic surveys. Although the sections do not show exactly the subsurface portion, the geology does not differ significantly from one area to another, hence the differences in image content and quality are mainly due to differences in acquisition and processing. With clearer sections compared to 2D acquisition.26

Figure 14. Three-dimensional (3D) seismic image



Source: Principles of 2D and 3D seismic interpretation. Chapter 4, 3D Seismic, 2004. Modified by the authors.

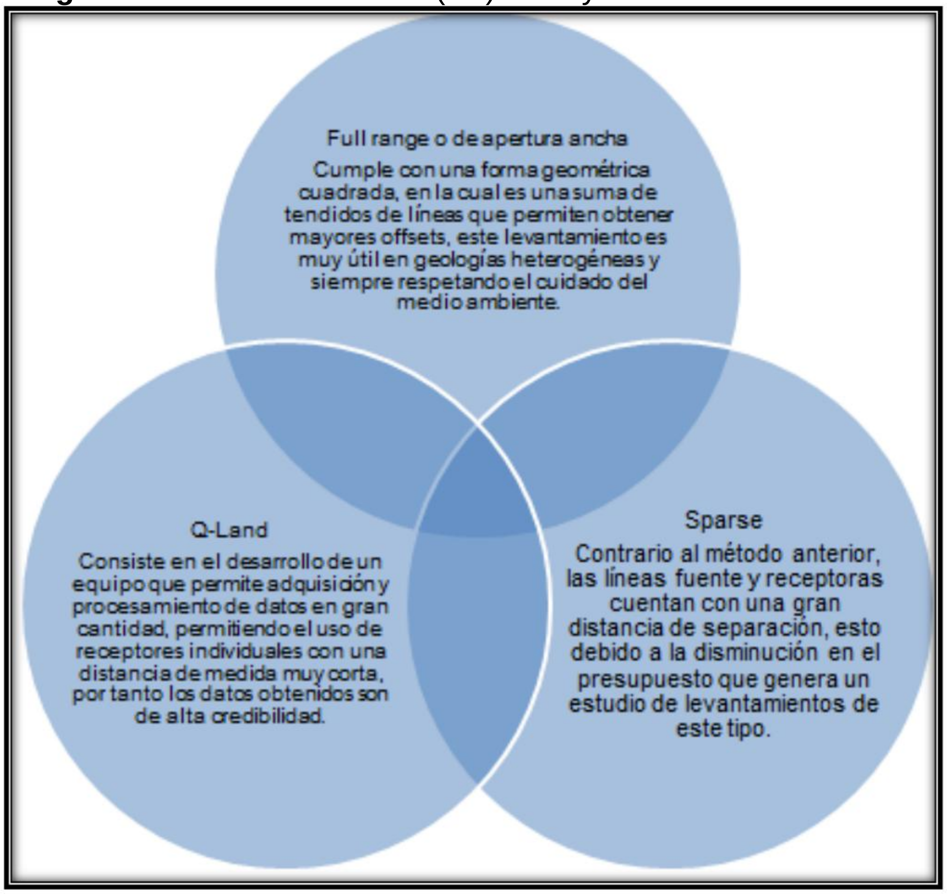
With 3D surveying you can obtain:

- The geological setting and details of the environment
- Geological tops with depths in the areas that merit it
- Study elements such as seismographs
- Coordinates of the area of interest

Among the most important 3D seismic data acquisition survey distribution methods are illustrated in Figure 3.

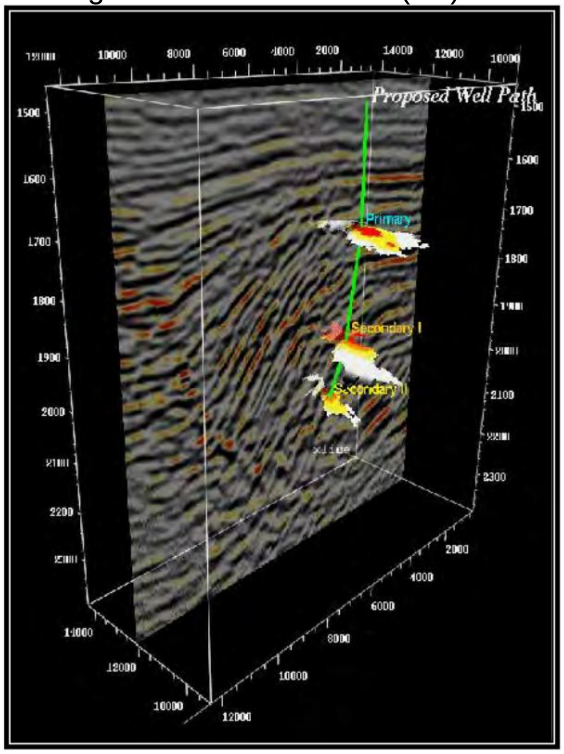
[26] BRIAN KENNETT, Seismic Wave Propagation in Stratified Media, 2009.

Figure 3. Three-dimensional (3D) survey distribution



Programs such as voxel displays can be used to help plan well trajectories based on 3D seismic data acquisition. For Figure **15,** the proposed types are shown.

Figure 15. Results of interpretation of seismic images in third dimension (3D)



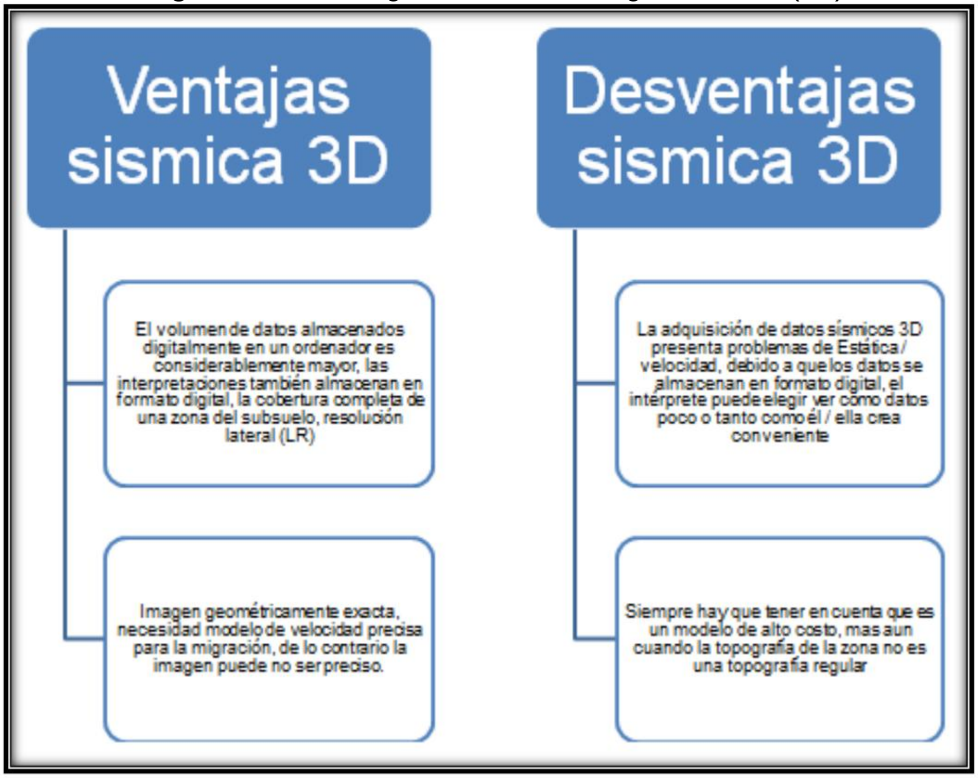
Source: Principles of 2D and 3D seismic interpretation. Chapter 4, 3D Seismic, 2004. Modified by the authors.

These software programs allow the 3D data volume to be viewed from a variety of perspectives such as: line ("Inline"), trace ("crossline"), arbitrary lines, time interval, slice horizon ("amplitude map"), strata slice, interpretation visualizations (horizons, faults), cube, Voxel displays.

3D seismic data can be viewed as lines (inlines) or traces (also called crosslines) or arbitrary cut lines through the volume of the seismic data.
data. These slices resemble 2D seismic slices, the main advantage being the arbitrary line that can be viewed from any angle chosen by the interpreter. With 2D lines the interpreter is forced to view the data in the orientation that it is acquired.

The advantages and disadvantages of the two-dimensional (3D) seismic data acquisition method, corresponding to **Figure 16,** are shown below .

Figure 16. Advantages and disadvantages, Seismic (3D)



2.1.6.4 4D seismic. This type of seismic survey differs from 2D and 3D in that the technique of detecting pressure and saturation variations in order to locate new exploratory projects or increase the production of different fields, the sum of all this information allows to build maps that identify faults and subsidence in the study area, this data collection allows to characterize the flow of fluids in the reservoir.

A disadvantage of seismic data acquisition is the noise that is governed by the study environment, either by affecting the wavelength reflected in the seismic signal. In addition to thickness limitations, there are other factors that limit the final resolution of seismic data; the ground acts as a filter that progressively attenuates the high frequency components of the seismic data, the acoustic velocity increases with depth due to compaction and the increase in this is reflected in the waveform of the signal, impairing resolution. With the existence of environmental noise, the processing data eliminates the frequency necessary for a finer resolution and the seismic signals consist largely of seismic "noise". Occasionally, the irregular pattern of the records is interrupted by a disturbance that rises above the background noise with a well, the characteristics are due to the excitation of seismic waves, far from the receiver, by some natural or artificial source.

Both 2D, 3D and 4D seismic data collect and interpret information for hydrocarbon exploration and exploitation, although 3D seismic has become the tool of choice in most cases. Seismic data are typically stored in digital format using PC or workstation-based software (e.g. SeisWorks, SeisVision). These packages typically allow 2D and 3D scenario modeling of seismic data, but will always seek to identify structures conducive to hydrocarbon storage and not to identify and detect fluids in economically exploitable quantities.

Although seismic waves pass through the Earth, they lose energy due to the geometric effect of the broadening of the wave front and due to the Earth's intrinsic absorption. However, in most cases the loss due to scattering and absorption is relatively small, so this attenuation of seismic energy is a small disturbance in the propagation process, but it must be taken into account that there will be losses in the process.

Among the main data that can be obtained in this data acquisition are:

- Depths of the strata
- Characterization of the basement
- Identification of groundwater sources
- Identification of geological zones with possible hydrocarbon accumulations
- Calculation of elastic parameters of the subsoil from wave velocities (P and S)
- Study of subsoil stratigraphy and geometry

2.2 ELECTRICAL RECORDS

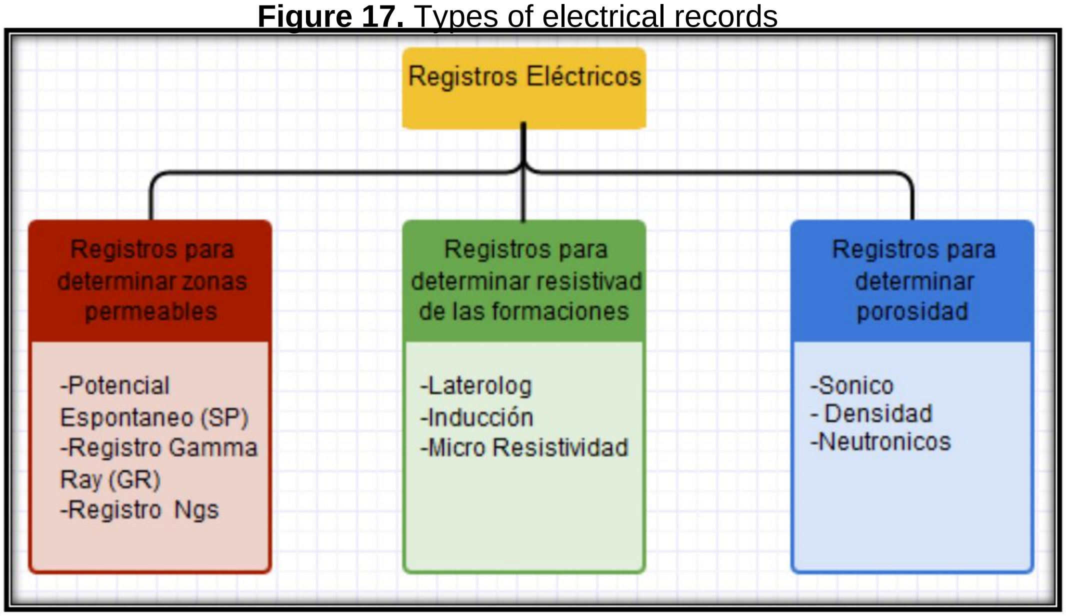
Once the exploratory stage of a well is completed, an electrical log is taken which will help to identify the different layers or strata present in the well; electrical logs allow the physical properties of the rocks surrounding a well to be established, whether in water, oil or mining, by means of a series of probes. These probes located inside the well can obtain data based on the depth, which are then used to generate a graph known as a well log.

With these records we can primarily obtain indications of permeable areas, rock porosity, positions of the stratum boundary (as in the case of coals in the density record), correlation of strata between perforations.

Electrical records are a conventional tool but it must be taken into account that their high cost has led to the emergence of new technologies, which use a different principle to obtain the same data and at different costs with a much shorter time ratio.

Figure **17** defines the types of electrical records to be explained in this chapter:

Figure 17. Types of electrical records



Source: Schlumberger, Principles/Applications of Log Interpretation. Modified by the authors

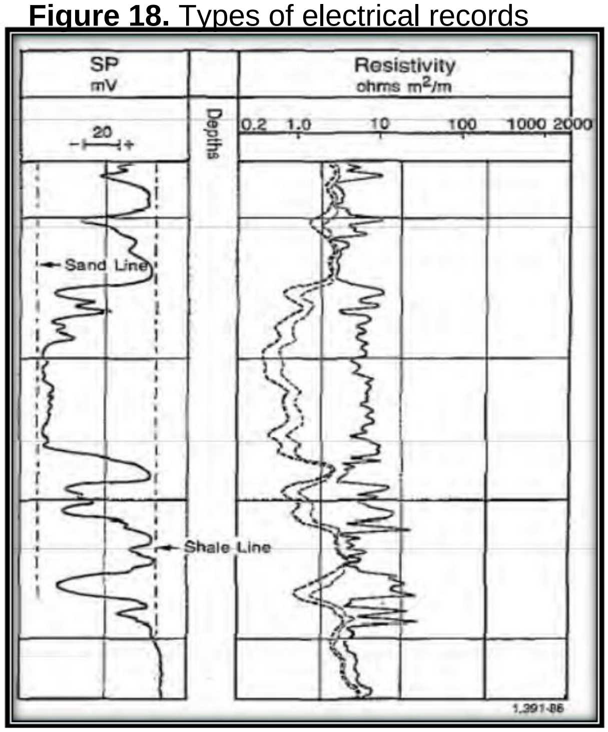
2.2.1 Logs to determine permeable zones. The importance of being able to find a permeable zone lies in one of the conditions for the generation of oil, since there must be a permeable rock in such a way that under pressure the oil can move through the microscopic pores of the rock, keeping in mind that the reservoir rocks have good porosity and permeability to allow the accumulation and flow of fluids and gases.

2.2.1.1 Spontaneous potential (SP). It is a record of physical phenomena that occur naturally in rocks. It is recorded through a curve that reflects the interaction of formation water, conductive drilling fluid and certain rocks. It measures the potential differential between a mobile electrode in the well and the fixed potential of an electrode on the surface. The SP curve presents variations, which are due to the current flow within the mud, which are produced by electromotive forces of electrokinetic or electrochemical origin.

The SP is measured in millivolts (mV). This record allows the identification of lithology and, based on this information, certain conclusions can be drawn about permeability. To read the SP curve, the salinity of the drilling mud and the salinity of the formation water must first be taken into account, since the SP will have different behaviors depending on the values of the data previously obtained.

An example of an SP register is shown in **Figure 18 ,** which is always The measurement starts from the sand line or the shale line, which are drawn at the values furthest to the right and left of the curve. If the salinity of the mud is greater than that of the formation water, the sand line will be the value furthest to the left of the curve, so the SP values will be positive. The higher these values are or the curve shows a trend to the right, the more likely we are to be in a shale zone. If the salinity of the mud is less than that of the formation water, the shale line is drawn at the point furthest to the right of the curve and negative SP values will be obtained.

Figure 18. Types of electrical records



Source: Principles and Applications of the Interpretation of SCHLUMBERGER Records

SP curves are used for:

- Detect permeable layers (areas-limestone-dolomites)
- Locate boundaries between units and determine their thickness

- Correlate lithological units and help define depositional models.
- Estimate the clay content of the reservoir rock.
- Identification of failure steps.

Factors affecting spontaneous potential (SP):

- Reservoir depletion.
- Invasion diameter, shale inclusions.
- Layer thickness, low permeability, fractures and faults. Formation
- temperature and resistivity.
- Type of fluid used in drilling (Mud).

2.2.1.2 Gamma Ray Log (GR). It is a measurement of the natural radioactivity of the Formations. It measures the natural radioactivity of the Formations through the emission of high-energy electromagnetic waves by the disintegration of radioactive elements. Some elements involved in the natural radioactivity of the Formations are potassium 40 (K40), Uranium (U), etc. These elements are generally found in clayey Formations (shales), which react with electromagnetic waves producing high GR values in the curve.

Gamma Ray is measured in API units, the higher the GR values, the more radioactive isotopes the formation contains, which is why we are in the presence of a clayey zone.

Table **2** shows some minerals with their respective reading value in API units:

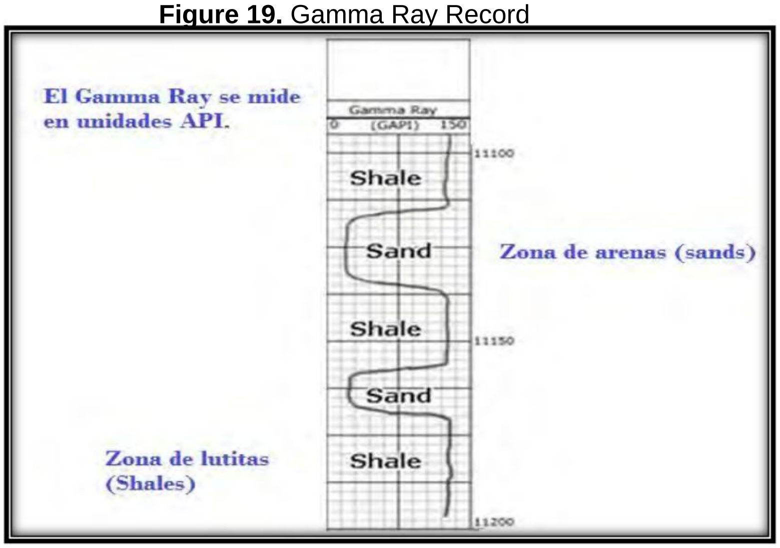
Table 2. API ranges according to rock type

Mineral	Gamma Radiation (API units)
Pure mineral	
Calcite	0
Dolomite	0
Quartz	0
Lithology	
Limestone	5-10
Dolomite	10-20
Sandstone	10-30
Shale	80-140
Evaporites	
Halite	0
Anhydrite	0
Silvina	0
Gypsum	500
Others	
Sulphides	0

Source: Range of radioactivity values for common lithologies (modified from Glover, P. MSc Petrophysics Course Notes)

Figure **19** shows a Gamma Ray log, in which the profile is used to correlate with the SP in determining lithology, in addition to simplifying the work because the salinity of the mud or the formation no longer needs to be verified.

Figure 19. Gamma Ray Record



Source: modified by the author taken from Principles and Applications of Record Interpretation SCHLUMBERGER

Gamma Ray Log (GR) profiles are used for:

- Cased well correlation.
- Definition and correlation of strata.
- Detection of radioactive tracers.
- Evaluate coal layers.
- Evaluate radioactive minerals.
- Indicator of shale content.
- Positioning of the drilling guns.

Factors affecting the Gamma Ray (GR) Register

- Hole diameter and density •
Thickness of the formations
- Eccentricity and probe diameter
- Detector type •
Profiling speed

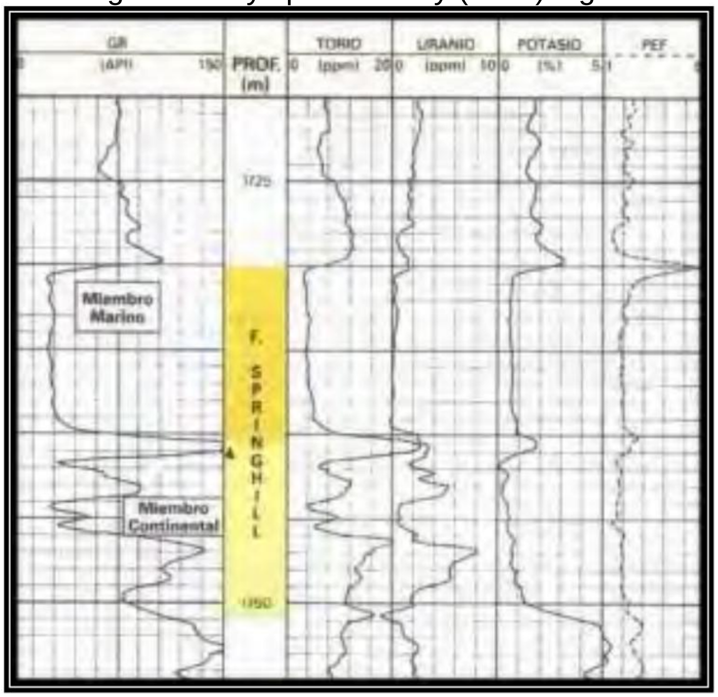
2.2.1.3 Natural Gamma Spectrometry (NGS) Logging. The NGS tool uses a sodium iodide scintillation detector contained in a pressure box which is held against the borehole wall by a biased spring during logging.

Gamma rays emitted by the formation almost never reach the detector directly. Instead, they are scattered and lose energy through three possible interactions with the formation: photoelectric effect, Compton scattering, and pair production. Because of these interactions and the detector's response to scintillation of sodium iodide, the original spectra are converted into smeared spectra.

Like the GR log, the NGS or Natural Gamma Ray Spectrometry log measures the natural radioactivity of the Formations. Unlike the GR log which only measures total radioactivity, this log measures the number of gamma rays and the energy level of each and allows the determination of the concentrations of radioactive potassium, thorium and uranium.

The log provides the concentrations of Potassium (in percentages), Thorium (in ppm) and Uranium (in ppm) in the formation, a clear example of the log is presented in **Figure 20.**

Figure 20. Natural gamma ray spectrometry (NGS) log



Source: Principles and Applications of Record Interpretation SCHLUMBERGER

Natural Gamma Spectrometry (NGS) Registry profiles are used to:

- Calculate volumes of clays
- Identify type of clay
- Identify and evaluate radioactive minerals

Factors affecting the Natural Gamma Ray Spectrometry Record (NGS):

- Hole diameter and density • Thickness of the formations
- Eccentricity and probe diameter
- Detector type • Profiling speed

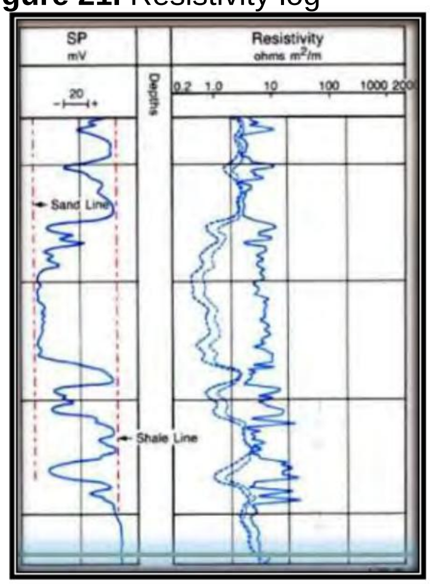
2.2.2 Resistivity logs. These are profiles that identify the property of fluids to allow electric current to flow. Resistivity means greater impediment to the flow of current, and hydrocarbons and fresh water are highly resistive hydrocarbons. Two curves are obtained from these logs, the short normal and long normal, the difference between these two readings is due to the distance between the electrodes.

In the case of the short normal, the separation between the electrodes is 16 inches, and measures the resistivity of the washed zone (Rxo). While in the long normal, the separation is 64 inches and measures the true resistivity (Rt). This difference between the separation of the electrodes is due to the fact that the greater the separation, the greater the area within the deposit will be covered by the current. The resistivity units are ohm-m.

High resistivity readings reflect high hydrocarbon content in the formation, since these are non-conductive fluids. On the contrary, low resistivity readings will indicate high presence of water in the formation, called wet sands, since water is a conductive fluid. In the log, resistivity increases to the right as reflected in the example log in **Figure 21.**

Resistivity is the key to determining hydrocarbons.

Figure 21. Resistivity log



Source: Principles and Applications of Record Interpretation SCHLUMBERGER

Resistive registers are divided into:

- Latero log
- Induction
- Micro resistive

2.2.2.1 Side-log logging. A very low frequency current flows from the tool, through the hole and into the formation. Focused electrode arrays around the logging electrode source force the measurement current into the formation in a horizontal disk-shaped direction around the wellbore. The focused electrodes emit a current of the same polarity as the logging electrode, but are located above and below it, preventing the main current from flowing up the salt-filled hole. Formation resistivity is determined by monitoring the amount of current flowing from the tool into the formation.

The effective depth of investigation of the latero log is controlled by the extent to which the main stream is focused; deep latero log readings are focused more intensely than shallow readings since the tool must be in direct electrical contact with the formation.

The Latero log tool represents one of the technologies used to measure formation resistivity. The tool is designed to operate in a conductive mud (water base). The tool sends focused current into the formation to measure the voltage in a specific volume of the formation. This voltage is related to the formation resistivity. The volume represents a shallow and deep investigation depth that allows shallow (LLS) and deep (LLD) resistivity measurements to be made.

Lateral log profiles are used to:

- Calculate Fluid Saturation, Sw, via Archie Equation
- Correlation
- Geopressure Detection
- Indicate Permeable Zones
- Measurement of the true resistivity (in virgin zone) of the Formation, Rt
- Measuring Invasion Diameter

Factors affecting the Latero log:

- Hole diameter •
Layer thickness
- Invasion
- The clays

2.2.2.2 Micro resistive electrical logs. Electrical current is forced into the formation by closely spaced electrodes mounted on pads pressed against the walls of the hole. Some designs such as the Micro Spherical Focused Log (MSFL) use focused electrodes similar to those of the lateral log, while older designs such as the Micro Spherical Focused Log (MSFL) use focused electrodes similar to those of the lateral log.

log, do not focus the current. By knowing the resistivity of the invasion fluid, Rmf, and making some assumptions about the fluid saturation in the washed zone, the porosity of the formation can be better estimated.

Micro resistive electrical log profiles are used for:

- Calculate water saturation in the Washed Zone, Sxo by means of Archie
- Define thin layers
- Identify fractures
- Indicate Permeable Zones
- Measure Formation Resistivity in the Washed Zone, Rxo

Factors affecting micro resistive electrical registers:

- Hole diameter •
Layer thickness
- Invasion
- The clays

2.2.2.3 Electrical induction logs. Their physical principle is based on transmitter coils that emit a constant alternating current of high frequency. The resulting alternating electromagnetic field induces currents in the formation. These currents flow as disks perpendicular to the axis of the tool and create electromagnetic fields that induce signals towards the receiver coils, that is, the receiver coils sense the formation response, both in magnitude and phase. This response is proportional to the conductivity of the formation (the inverse of resistivity). Multiple transmitter and receiver coils are used to minimize the effects of the hole and invasion on the tool. The most modern versions of the tool make better measurements, digitally recorded, of the input and output phase of the signal, and operate at different frequencies to improve the accuracy of the tool. Accuracy is greatly improved by environmental corrections made in real time. Tool arrays may have many receivers, usually at close spacings, and rely on signal processing to create a common vertical resolution for all formation resistivity measurements at different frequencies and different distances from the hole.

Induction Electrical Logs profiles are used for:

- Calculate Fluid Saturation, Sw, via Archie Equation
- Correlation
- Indicate Permeable Zones
- Measuring Invasion Diameter
- Measure the True resistivity (in virgin zone) of the Formation, Rt

Factors affecting electrical induction registers:

- Hole diameter •
Layer thickness
- Invasion
- The clays

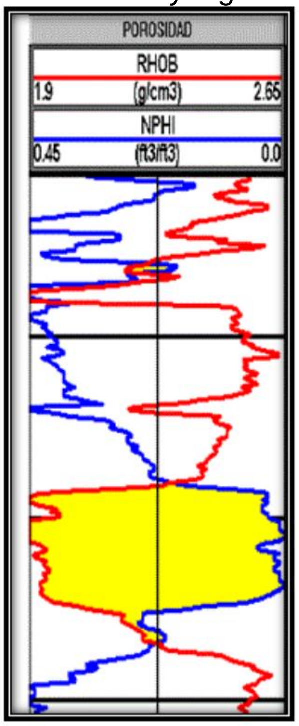
2.2.3 Porosity logs. To analyze a porosity log, the following logs must be available:

- Neutron Records
- Density Record
- Sonic Record

The readings of these tools are affected by porosity, fluids and matrix in the formation. If the effects of fluids and matrix are known, the response of the tools can be related to porosity.

Figure **22** is an example of a porosity log, which will be explained further below under each type of log.

Figure 22. Porosity log



Source: Principles and Applications
of Data Interpretation
SCHLUMBERGER Records

2.2.3.1 Neutron Records. It is the response to the amount of Hydrogen present in the training.

This record, together with the density record, can determine the existence of liquid or gaseous fluid. Due to the excavation effect, in which the neutron porosity curve goes to the right while the density porosity curve goes to the left, in this case and due to this effect it can be said that this area contains gaseous fluid. If the value recorded by both curves presents similar values, it is said that liquid fluid exists.

To read these curves, a series of environmental corrections must be taken into account, which will modify the values read from the records, as well as the porosity and density values.

It is necessary to have information from records when making correlation, in order to identify prospective areas, estimate the type of fluid, porosity and density of the matrix. The information from one record to another should not contradict each other, but on the contrary should confirm the information provided, for example, in a case where the SP indicates that it is sand, the GR should also indicate the same, otherwise everything is in the hands of the person in charge of interpreting that information, who should explain in a logical way the reason why that happened.

Profiles are a necessary information tool when evaluating any deposit, as they provide vital information about it, since they measure lithology, porosity, density and through a series of equations and corrections, saturations and finally POES and Recovery Factor can be determined.

Porosity by this method is determined by reading directly from the obtained log, that is, as defined in **Equation** 1:

Equation 1. Neutron Porosity

$$\emptyset = \emptyset_N = \emptyset_{NCL}$$

Source: Principles and Applications of Record Interpretation, Schulmberger (2010)

Among the tools used to run neutron records, we have:

- Compensated Neutron. (CNL)
- Dual Porosity Neutron. (CNT-G)
- Gamma-Neutron CCl.

- GNT Series.
- Dual Spaced Epithermal Neutron.
- Sidewall Neutron Porosity. (SNP)
- Dual Spaced Neutron II.

Neutron Logging profiles are used for:

- Calculate porosity in layers of known lithology.
- Detect gas-saturated reservoirs in clean formations.
- Evaluate Formation lithologies in combination with density Verify consistency of
- observed lithologies with mudlog, GR and density.

Factors affecting the Neutron Record:

- Effect of salinity.
- Stand-Off effect or lack of separation between the tool and the wellbore wall.
- Effects of lithology. • Mud weight. • Hole size. • Temperature and pressure.

2.2.3.2 Density Log. Its basic principle is that a radioactive source placed against the well wall emits medium-energy gamma rays into the formation. These particles collide with the electrons in the formation at high speed and lose part of their energy in each collision. The scattered gamma rays that reach the detector are counted to determine the density of the formation.

Porosity is determined by the formula present in **Equation** 2:

Equation 2. Porosity density

$$\emptyset = \emptyset_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

Source: Principles and applications of the Interpretation of records, schulmberger (2010)

Where: : Porosity, %.
: Matrix density (gr/cc)

: Gross density (measured at reference point), (gr/cc)
: Fluid density (depending on the fluid, if it is water the data is taken as 1.71 gr/cc)

Table **3** presents the densities of the most commonly used rocks:

Table 3. Rock density values Rock Density (g/cm3)

Sandstone (unconsolidated)	2.1
Sandstone (Semi-Consolidated)	2.2
Sandstone (consolidated)	2.6
Shale	1.9 – 2.7
Limestone	2.6
Dolomite	2.8
Anhydrite	2.98
Breath	2.03
Coal	1.17 – 1.80

Source: Principles of 2-D and 3-D Seismic Interpretation. Chapter 1, Rock Properties I, 2004. Modified by the authors.

The tools used to run the density records:

- Spectral Density. (LDT)
- Lithodensity. (LDT)
- Express Platform. (PEX).

Factors affecting the Density Record:

- Effect of hydrocarbons.
- Hole effect. •

Thickness of plaster.

- Fluids present in the investigated area.
- Lithology of the Formations.

2.2.3.3 Sonic Logging. Its physical principle is based on the work performed by a transmitter that emits sonic impulses and a receiver that captures and records the impulses. The sonic profile measures the transit time of a compressional sound wave through the formation (the time is the inverse of the speed of the sound wave). The fundamental objective of this is to measure the porosity of the formation, which will depend on the lithology of the formation and the nature of the fluids that fill the porous spaces. Porosity is determined by means of the formula present in Equation 3:

Equation 3. Sonic porosity

$$\varnothing = \varnothing_S = \frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$$

Source: Principles and applications of record interpretation, Schulmberger (2010)

Where:

: Porosity, %.
: Matrix transit time (ƒÝs/ft)
: Read transit time (measured at reference point), (ƒÝs /ft)
: Fluid transit time (depends on the fluid, for water it has a value of 189 ƒÝs /ft)

Sonic Logging profiles are used for:

- Calculate porosity in layers of known lithology.
- Calibrate seismic data.
- Combined with the density record, it is used to generate seismic traces.
- Evaluate secondary porosities in combination with density and neutron tools.

Factors affecting Sonic Recording:

- Hole diameter.
- Lithology.

2.3 RESULTS OF CONVENTIONAL METHODS

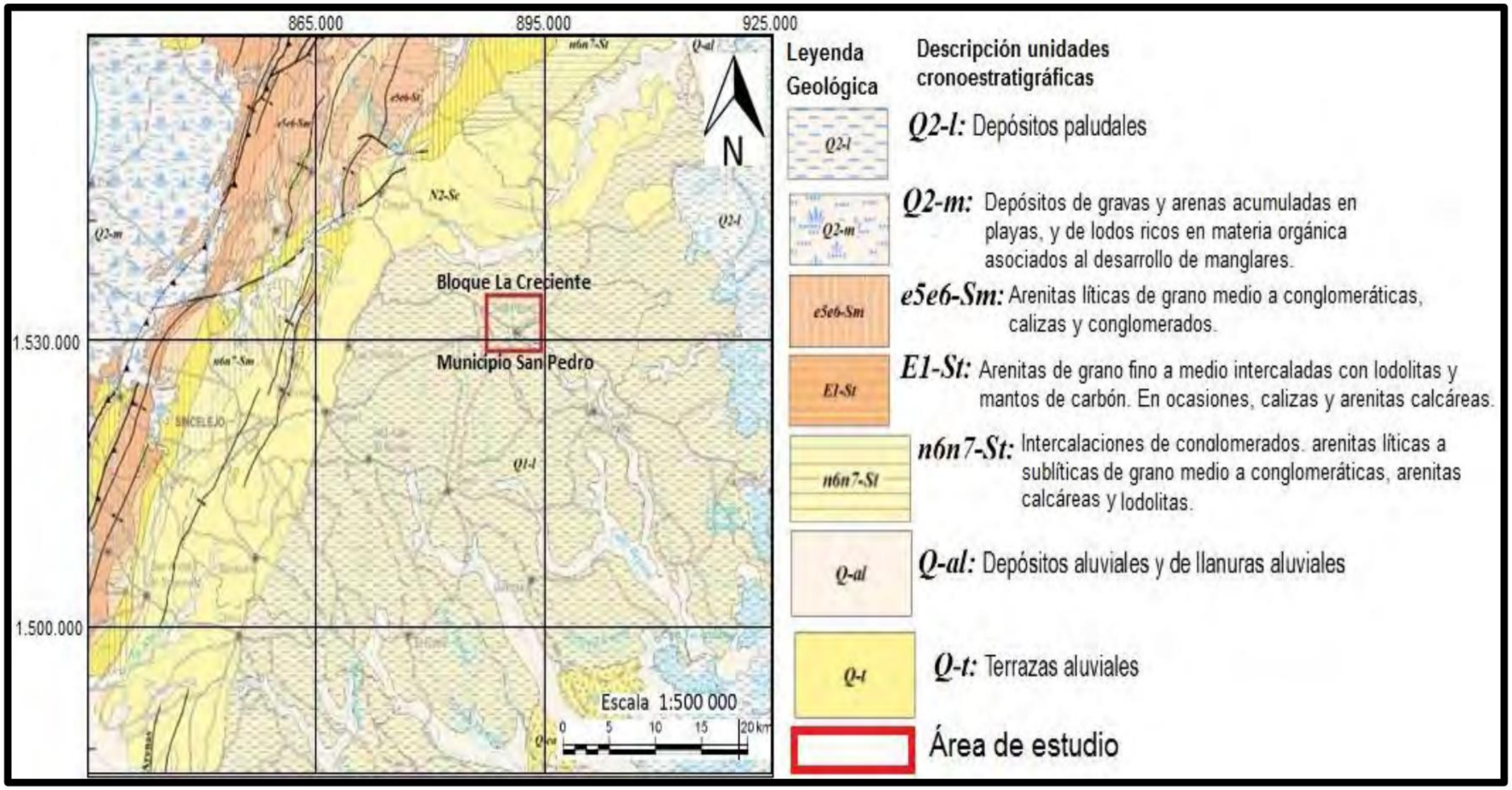
The chapter on results of conventional methods refers to the results obtained from conventional technologies, such as seismic recording and electrical recording.

For the La Creciente Block area of the Lower Magdalena Valley Basin, the company Pacific Rubiales carried out a structuring of a work plan, which is divided into a series of exploration activities in search of hydrocarbon prospecting areas. The contribution of each of these stages generates the characterization of an area suitable for hydrocarbon storage to define areas with commercial potential. It is important to highlight that these stages are exclusively for identifying prospective areas since, for reserve estimation plans, they can only be verified by drilling exploratory wells.

A geological map of the area obtained from the Colombian Geological Service allows us to observe the geology, geological time and deposits present on the surface. As a result, the areas suitable for hydrocarbon accumulation can be indicated.

Below is the La Creciente Block located in the Lower Magdalena Valley Basin, on the geological map of Colombia, as shown in **Figure 23.**

Figure 23. Geological terrain map of Colombia



Source: Colombian Geological Service, Geological Atlas of Colombia 2015, modified by the authors

From the geological map of Colombia it was concluded that the superficial geology of the area to be studied is of the paludal type, it consists of swamps or marshes, therefore the regional map in this area is composed of 90% by paludal quaternary deposits with small terraces and alluvial plains corresponding to the tributaries or rivers present in the area, the other 10% correspond to fine to medium grained sandstones interspersed with mudstones and coal seams.

Because it is located in the valley, the surface geology is not of great help in defining the stratigraphic sequence and existing structures **Figure 23.**

The study of satellite images of the area in the established references (567, 568, etc.) are generated in color tones referring to the presence of water, vegetation, among other environments, which allow us to differentiate that in the La Creciente Block braided rivers are observed (young valley), with drag of coarse materials, gravel, low vegetation (clays or silts) corresponding to a sedimentary area.

Based on aerial photographs observed using a stereoscope, a map will be created highlighting the areas conducive to hydrocarbon accumulation identified by the company's team of geologists.

The execution of field work consists of a topographic study that consists of the geomorphological study of the place to characterize the relief present in the area and a study of sampling, which is carried out by a selected group of geologists, these samples are processed in the laboratory.

in order to determine the corresponding age of the area.

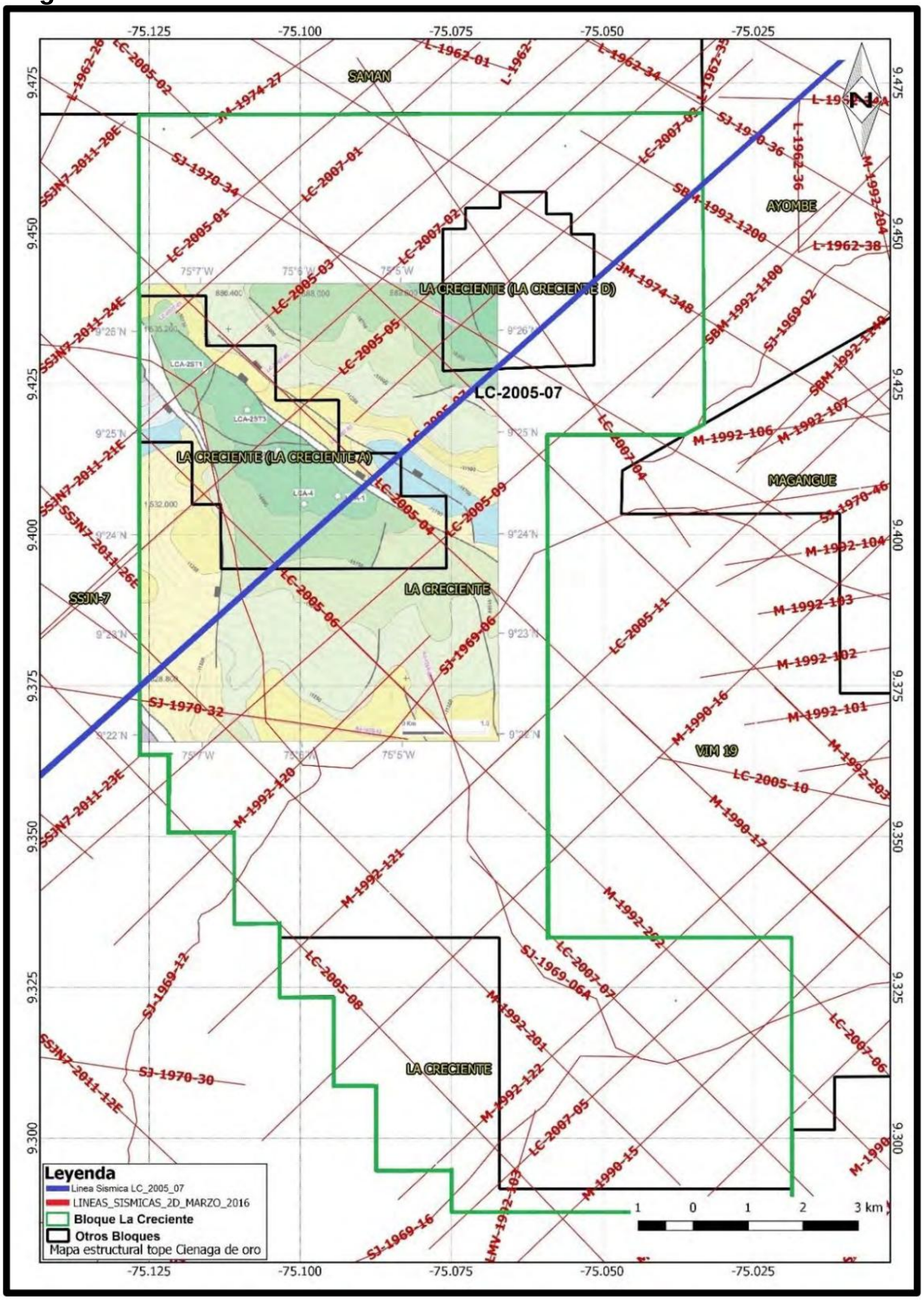
The combination of the previous stages allows us to estimate whether the area has favorable environments for the generation, accumulation and production of hydrocarbons, allowing us to decide whether it is worthwhile to conduct seismic surveys in the area in order to study the interior of the earth and look for the presence of structures favorable for the accumulation of hydrocarbons. If this is the case, a 2D seismic survey will be conducted with a view to taking it to greater detail in 3D seismic, to locate an area where an exploratory well can be planned.

2.3.1 Analysis of seismic log results. In 2005, the operator Pacific Rubiales Energy acquired the La Creciente Block area. A seismic study was subsequently conducted and analyzed with previous seismic studies in order to plan the La Creciente 1 well. The drilling result indicated that the producing interval corresponds to the Ciénaga de Oro Formation.

After identifying the Ciénaga de Oro Formation as a producing Formation, a series of 2D and 3D seismic studies were carried out in the La Creciente Block.

Figure **24** shows the location of the 2D seismic lines in the area of the La Creciente Block. The red lines correspond to the 2D seismic lines located in the Lower Magdalena Valley Basin, and the green line encloses the area of the La Creciente Block. The seismic line on which the analysis of the results of this chapter is based is the line called LC-2D-2005-07, which is marked in blue.

Figure 24. Location of 2D seismic lines in the La Creciente Block



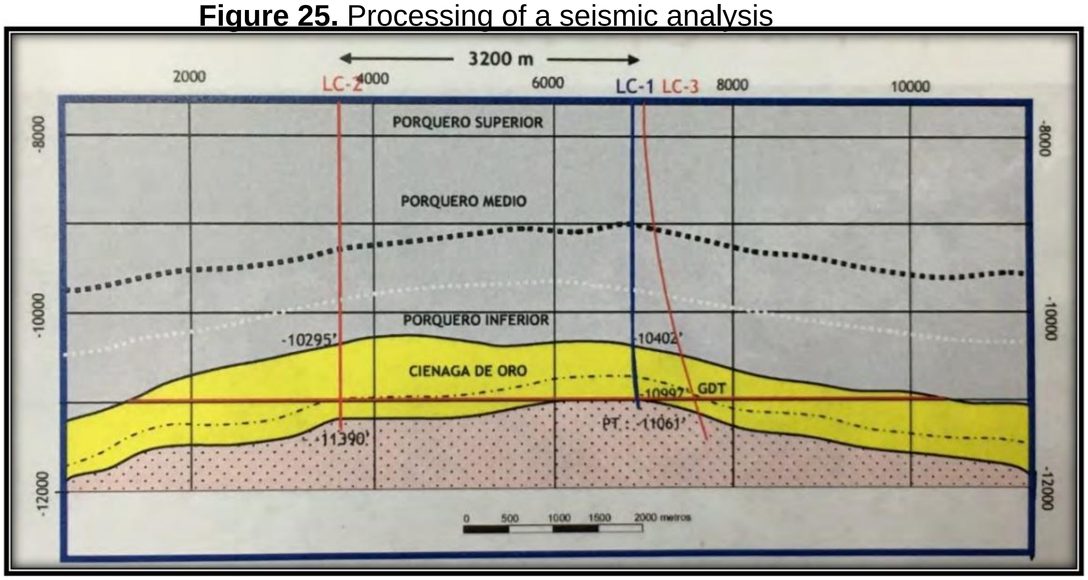
Source: data from seismic lines of the La Creciente Block, Colombia ANH (2016), modified by the authors.

The selection of the area to carry out the 3D seismic takes into account the location, the predominant direction of the structures, the depth of the study Block and the economic factor since its purpose is to be able to delimit the limits of the deposit more accurately.

With the information obtained from the seismic line LC-2D-2005-07 that allowed the drilling of the La Creciente 1 (LCA-1) well, two delineator wells were drilled to size the reservoir of the La Creciente Block, which were called La Creciente 2 (LCA-2) and La Creciente 3 (LCA-3).

Figure **25** is the interpretation of a seismic line, in which the LCA-1 well is projected with respect to its delimitation with LCA-2 and LCA-3.

Figure 25. Processing of a seismic analysis



Source: taken from the book Basins of the Lower Magdalena Valley volume 10 – ANH (2011).

The LCA-2 well was located 3,200 meters northeast of the LCA-1 well and the LCA-3 well was a deviated well which was located 74 meters from the LCA-1 well.

Figure **26** shows the predominant fault system in the La Creciente Field from a 3D seismic line.

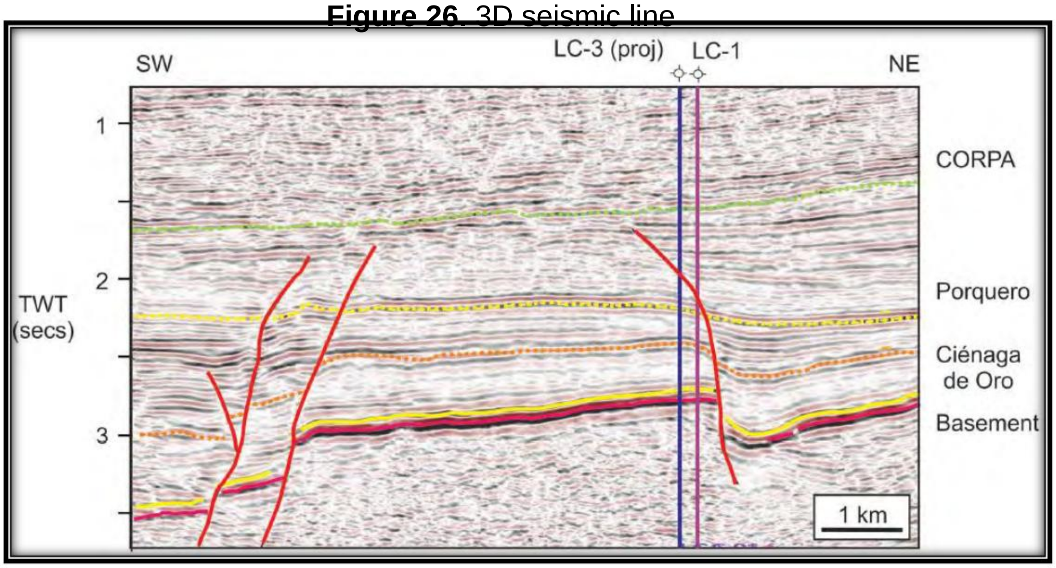
The 3D seismic shows the structural style of the La Creciente Field, which was obtained from the book Cuencas del Valle Inferior del Magdalena volume 10 – ANH (2011).

As seen in **Figure 26,** the violet vertical line represents the projected location of the LCA-1 well and the blue vertical line represents the projected location of the LCA-3 well, trapping the Ciénaga de Oro Formation, in the level of rotated blocks closing the gas contact with normal faults showing gentle tectonic inversion.

The colored lines present in **Figure 26** of the seismic section represent:

- Green line: Andean molasses base, Upper Miocene to Pliocene
- Thick yellow dotted line: Superior Porquero base
- Orange line: Base of Porquero Medio, a basin-wide unconformity in the Middle Miocene area
- Thin yellow dotted line: Ciénaga de Oro top (sands)

Figure 26. 3D seismic line



Source: taken from the book Basins of the Lower Magdalena Valley volume 10 – ANH (2011)

The lateral closure of the trap is due to favorable juxtaposition with shales of the Porquero Formation along the northeast limit of the trap, since it is a northwest-southeast trending normal fault.

After carrying out a seismic campaign that has allowed us to know what rocks and structures exist, such as in this area of the Lower Valley Basin of Magdalena, the presence of a thick Tertiary layer was evident, in addition to conditions that have allowed drilling wells in structures associated with the morphology of the basement, generated by the subduction of the Miocene epoch - Oligocene and the accumulation of sediments that together with genetic processes, associated with pressure and temperature, confirmed the presence of light hydrocarbons of the condensate type in Cretaceous rocks as source and storage rocks.

with the presence of limestone in the wells La Creciente 1, La Creciente 2, La Creciente 3, La Creciente 5, among others.

2.3.2 Analysis of electrical log results. Pacific Rubiales Energy conducted an electrical log study in 2015 to assess the presence of hydrocarbons in the La Creciente well (LCA-5). A Gamma Ray log present in a master log will be analyzed, as well as the chromatography and sedimentology components of the well to perform a stratigraphic analysis of the study area, which will later be compared with the results of the oil and gas exploration technology (OFT).

The electrical log was taken in well LCA-5, which is located 200 meters northwest of well LCA-1.

The objective of analyzing a Gamma Ray log is to be able to identify the lithology present in the formation as the depth increases and in turn compare it with the results of the trench samples.

The Gamma Ray log began to be run from 7,835 feet depth (MD) to the top of the basement which was found at 11,715 feet depth (MD), because the first feet were already known geology (corroborated by the mud logging test of the cuttings in the drilling) and it was known that it was not a sequence with producing potential.

It is noted that all analyses of each Gamma Ray segment and the analysis of trench samples from the master log were performed by the Geologist and ADT of the company providing service for this well.

From the master log record, the description of the present Formations was made from the youngest to the oldest:

• Corpa Formation: It has a thickness of 4,960 feet. This Formation is dominated by sandstones with clay intercalations. Its top was found at 30 feet depth (MD) and its base at 4,990 feet depth (MD). In this interval, the following lithologies were identified through the analysis of trench samples, as shown in **Figure 27:**

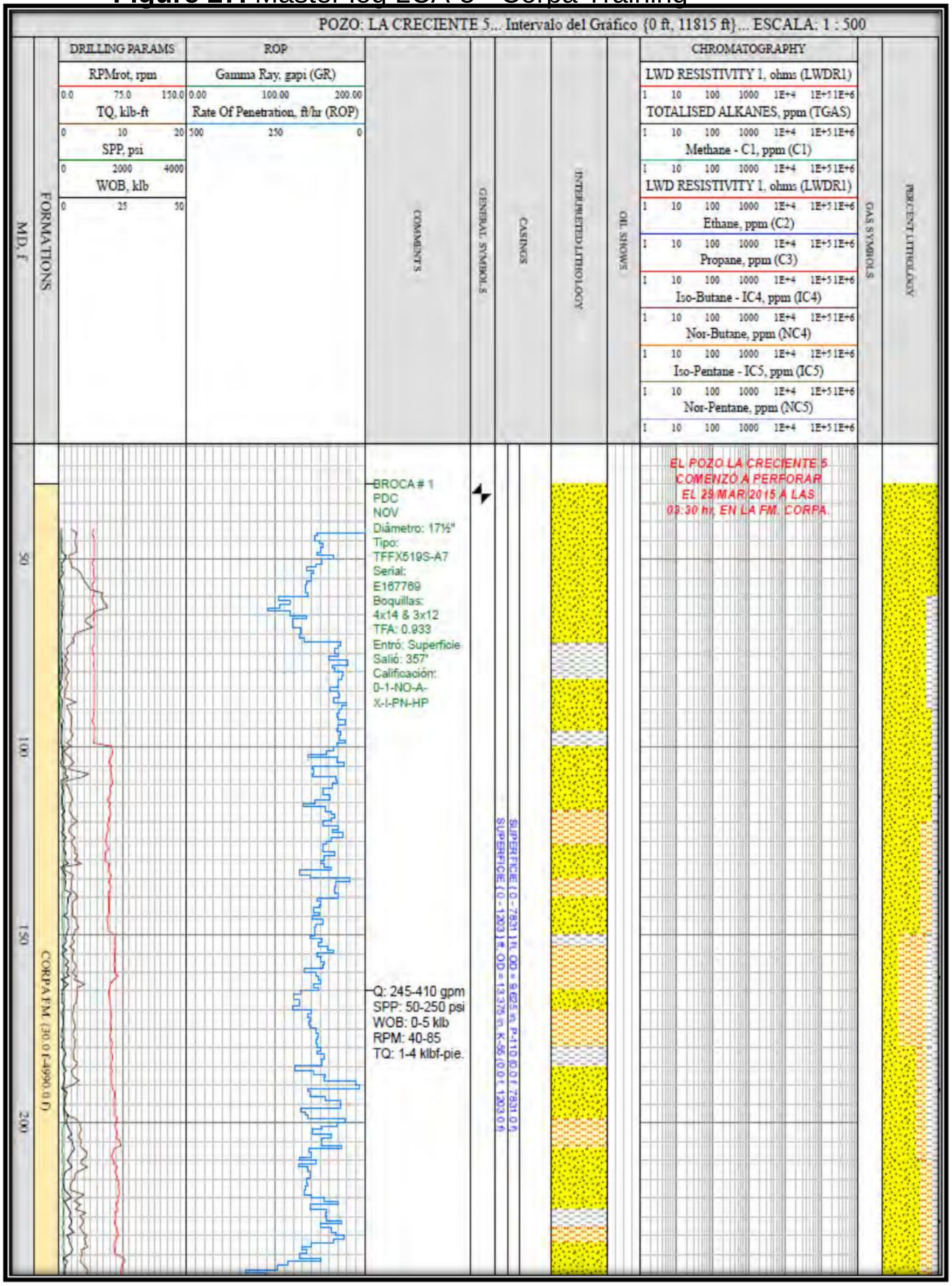
ÿ SAND. Sublithic; translucent white, light gray, hyaline; medium to fine grained, subangular to subrounded, subspherical, regular sorting; composed of: 80% quartz, 20% dark lithic fragments; no visible oil manifestations.

ÿ CLAYLITE. Light grey, occasionally white; moderately firm to soft; sub-bloc to blocky; slightly silty; moderately soluble; not calcareous.

ÿ SAND. Sublithic; translucent white, hyaline, less translucent yellow, locally light grey, dark grey, black, dark green, yellow; composed of 80% quartz and 20% dark lithic fragments, medium grain predominates, less coarse grain, locally fine grain, subrounded, subspherical, regular selection; without visible oil manifestations.

ÿ CLAYLITE. Light grey, yellowish grey, dark yellowish orange; moderately hard, less soft; blocky to sub-blocky; some silty; moderately soluble; not calcareous.

Figure 27. Master log LCA-5 - Corpa Training



Source: Master log LCA-5 provided by Pacific Rubiales

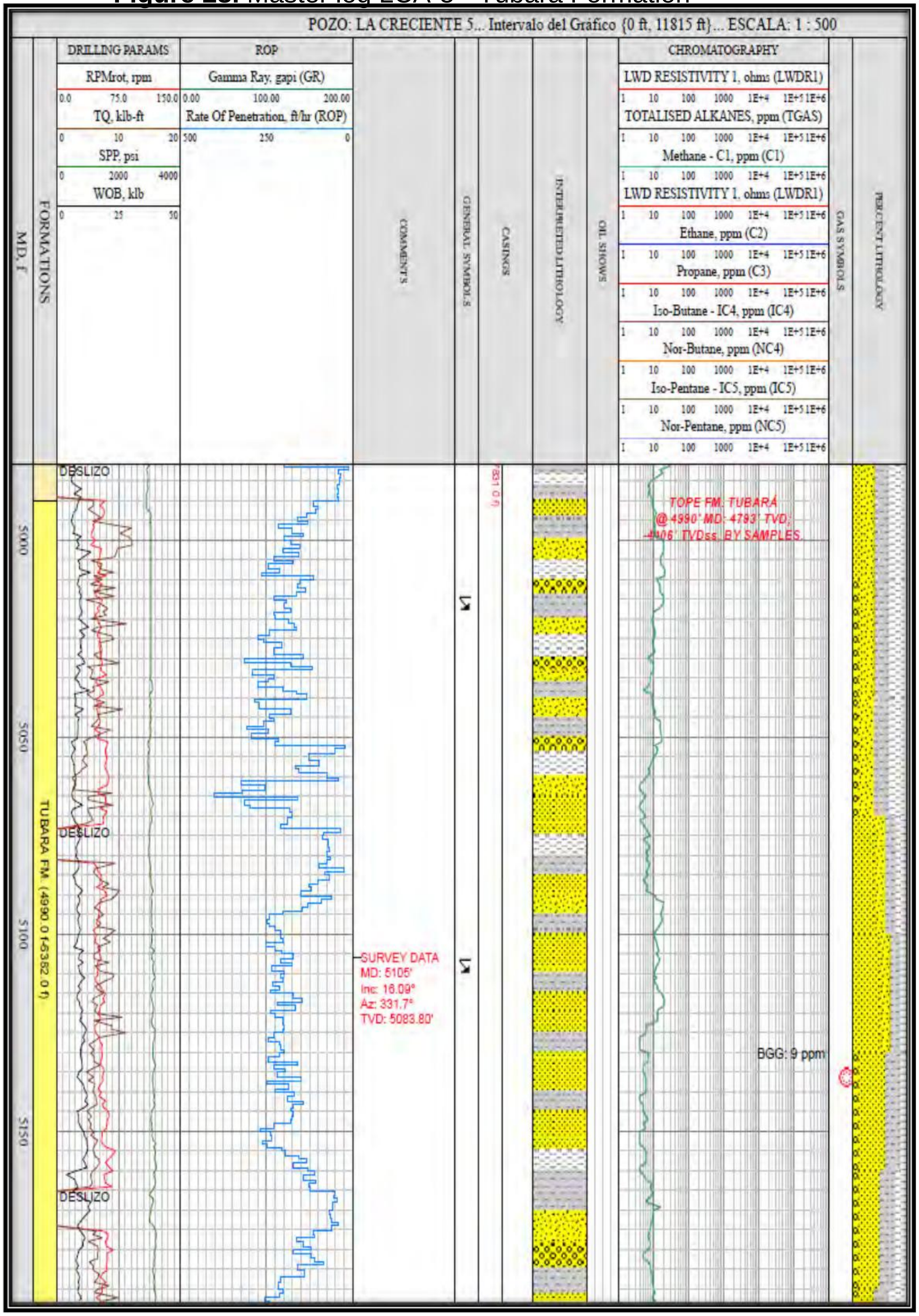
• Túbara Formation: It has a thickness of 1,392 feet. This Formation is dominated by sands with intercalation of conglomerates and clays. At 5,135 feet depth (MD) there is a background gas show of 9 ppm of methane. Its top was found at 4,990 feet depth (MD) and its base at 6,382 feet depth (MD). In this interval, the following lithologies were identified through the analysis of trench samples, as shown in **Figure 28:**

ÿ LOCAL CONGLOMERATIC SAND. Lithic; translucent, less milky white, smoky; medium to coarse grained, less very coarse, local granules, angular, subangular, poor sorting; composed of 60% quartz and 40% light yellow, light gray, light brown, black, chert (black, mustard) lithic fragments; no oil manifestation.

ÿ SANDSTONE. Sublithic; translucent, hyaline, light green, less greenish grey; very fine to fine grain, occasionally medium; subrounded to subangular, moderately sorted; clayey matrix; moderately friable; composed of 70% quartz and 30% lithic fragments predominantly green and black in colour; mica content is observed; no visible porosity; no manifestation of oil.

ÿ SILTSITE. Predominantly light grey, locally light brown; sub-bloc; moderately soft, locally hard-soft; not calcareous; occasionally graded to very fine-grained sandstone.

Figure 28. Master log LCA-5 - Túbara Formation



Source: Master log LCA-5 provided by Pacific Rubiales

• Porquero Upper Formation: It has a thickness of 2,365 feet. This formation is dominated by shales with a combination of sands and clays. The Gamma Ray log began to be run from 7,835 feet depth (MD), where it indicated an average reading value between 60 and 80 API corresponding to shales. At 7,850 feet depth (MD) a formation gas show of 3,216 ppm of methane is presented and at 7,990 feet depth (MD) a background gas show of 285 ppm of methane is presented. Its top was found at 6,382 feet depth (MD) and its base at 8,747 feet depth (MD). In this interval, the following lithologies were identified through the analysis of trench samples, as shown in **Figure 29:**

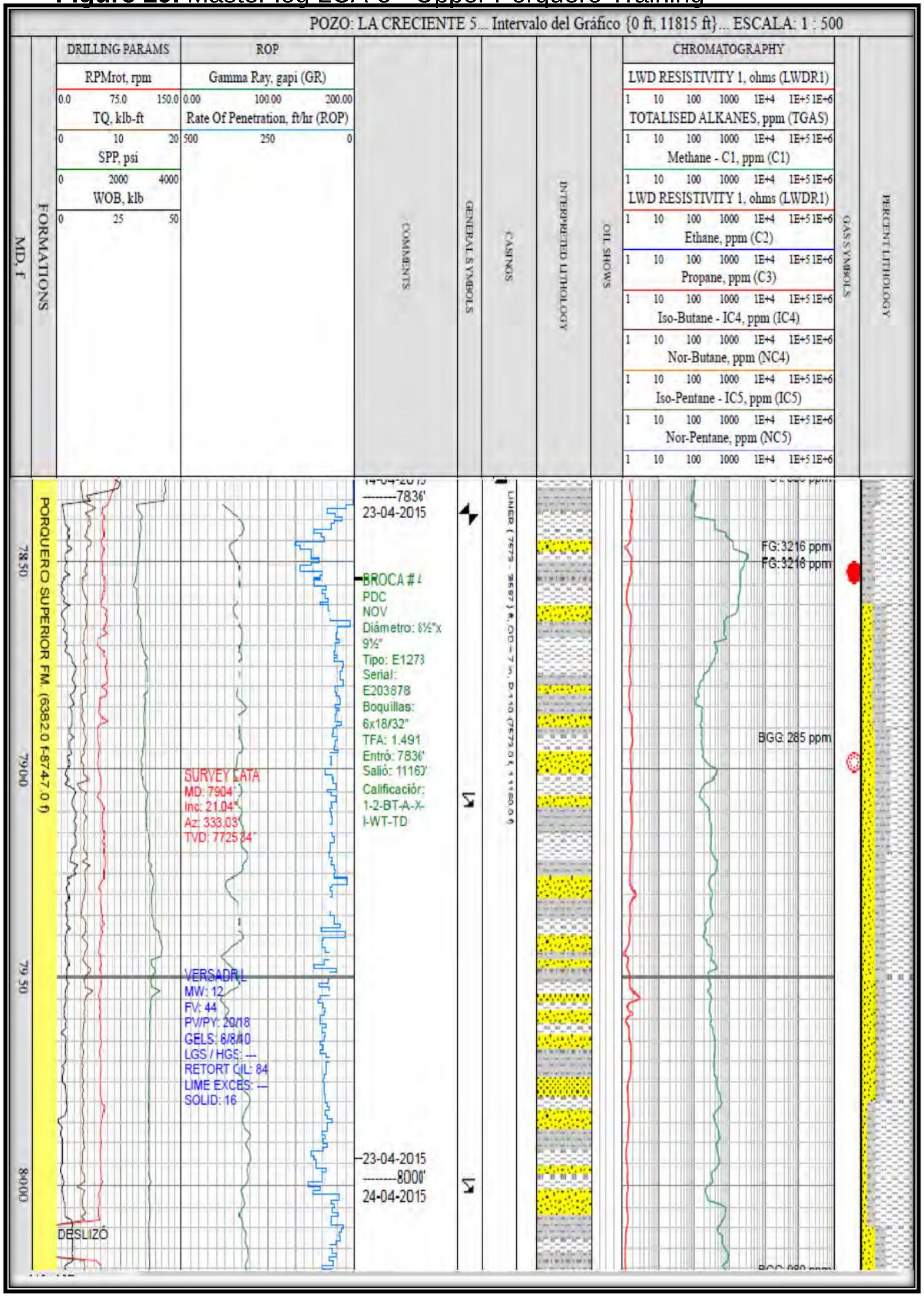
ÿ CLAYLITE: Medium to dark grey, less dark grey, occasionally light grey and light brown; moderately firm to firm, locally firm, occasionally soft; blobby, locally silty; not calcareous.

ÿ SANDSTONE. Sublithic; light grey, locally light greenish grey and light green and light brown, translucent, hyaline; friable, locally moderately consolidated; blotchy; fine grained, less often very fine, subrounded, occasionally subangular, subspherical, good sorting; composed of 90% quartz and 10% dark lithic fragments (green and black); locally calcareous cement, locally clayey matrix; poor visible porosity; no oil evidence

ÿ LIMESTONE. Micrite texture according to Folk, mudstone texture according to Dunham; white, very light grey, less light brown; soft, less hard (brown); sub-bloc, less bloc; poor visible porosity; no visible manifestation of oil.

ÿ SILTSITE. Medium to dark grey, less dark grey, occasionally light grey and very light brown; moderately firm to firm, locally firm, occasionally soft; blotchy, occasionally sublaminar; locally with dark laminations; locally graded to very fine-grained sandstone; not calcareous.

Figure 29. Master log LCA-5 - Upper Porquero Training



Source: Master log LCA-5 provided by Pacific Rubiales

• Porquero Medio Formation: It has a thickness of 718 feet. This formation is dominated by shales with clay intercalations. The Gamma Ray log indicated an average reading value between 65 and 70 API, which corresponds to shales. At 8,880 feet depth (MD), a background gas show of 3,120 ppm of methane is present. Its top was found at 8,747 feet depth (MD) and its base at 9,465 feet depth (MD). In this interval, the following lithologies were identified through the analysis of trench samples, as shown in **Figure 30:**

ÿ CLAYLITE. Medium to dark grey, occasionally medium grey and medium brown; moderately firm, locally firm, sublaminar, less blotchy; silty; locally with a lutitic appearance; not calcareous.

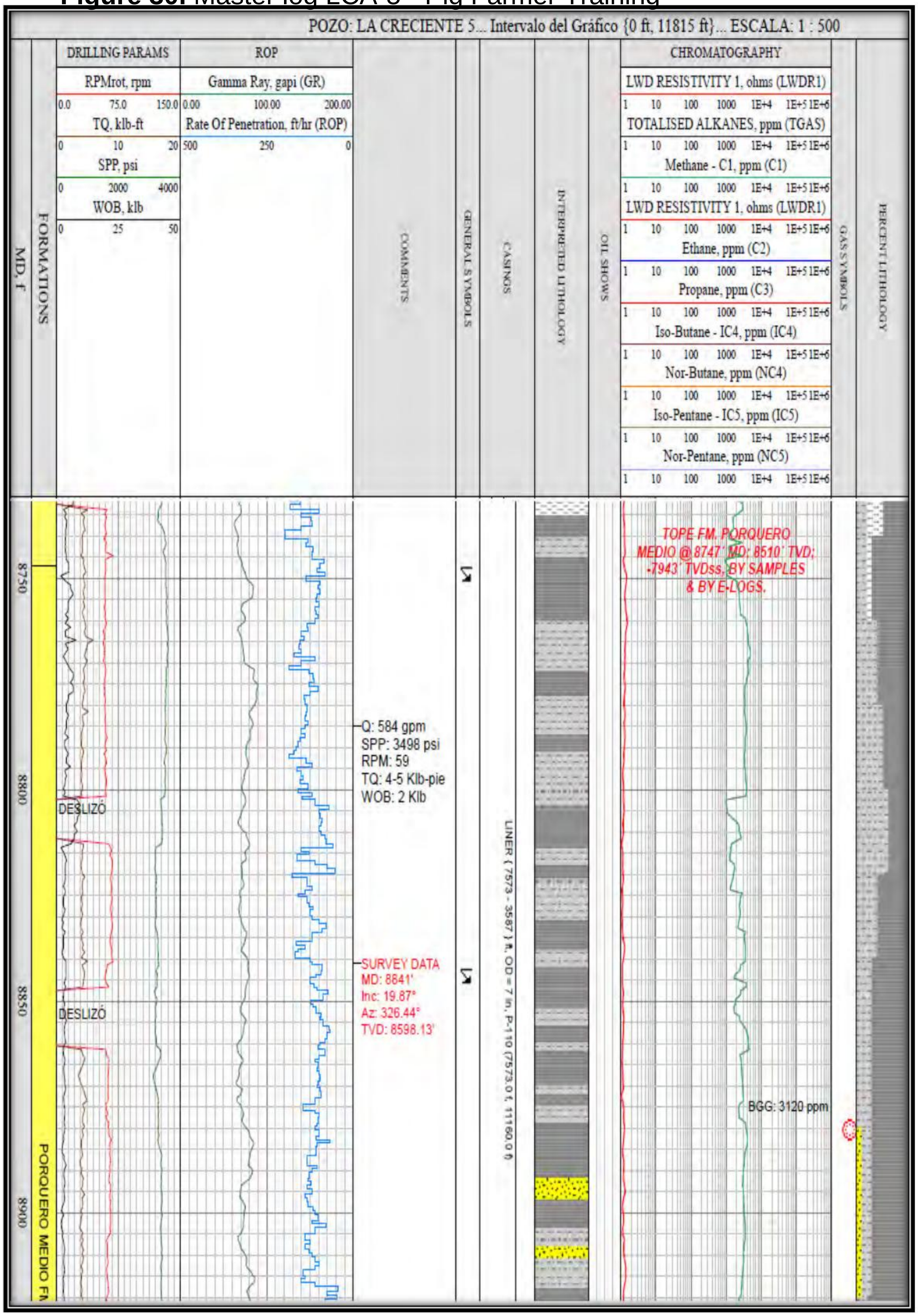
ÿ SAND. Quartzy; white and light grey, translucent, hyaline; very fine grain, sub-rounded, sub-spherical, good sorting; with traces of black lithic fragments; without visible oil.

ÿ SANDSTONE. Sublithic; medium greenish gray, medium gray; moderately consolidated, less friable; composed of 80% translucent white, hyaline quartz and 20% dark black and green lithic fragments, fine grained, subrounded to subangular subspherical, good sorting; with siliceous cement, some with clayey matrix; poor visible porosity; no visible oil manifestations.

ÿ SILTSITE. Medium to dark grey, less dark grey, locally medium to dark brown; moderately firm to firm, less firm; sublaminar, less subbloc, locally blocky; locally graded to very fine-grained sandstone; locally clayey; not calcareous

ÿ MALLETITE. Medium to dark grey, rarely medium to dark greyish brown; firm, less moderately firm; sublaminar, less laminar; fissile; sub-stillous, occasionally tabular; silty; micropyritic; locally slightly calcareous.

Figure 30. Master log LCA-5 - Pig Farmer Training



Source: Master log LCA-5 provided by Pacific Rubiales

• Lower Porquero Formation: It has a thickness of 1,692 feet. This formation is dominated by shales and clays. The Gamma Ray log indicated an average reading value between 60 and 70 API, which corresponds to shales. At 9,540 feet depth (MD), a background gas show of 4,175 ppm of methane is present. Its top was found at 9,465 feet depth (MD) and its base at 11,157 feet depth (MD). In this interval, the following lithologies were identified through the analysis of trench samples, as shown in **Figure 31:**

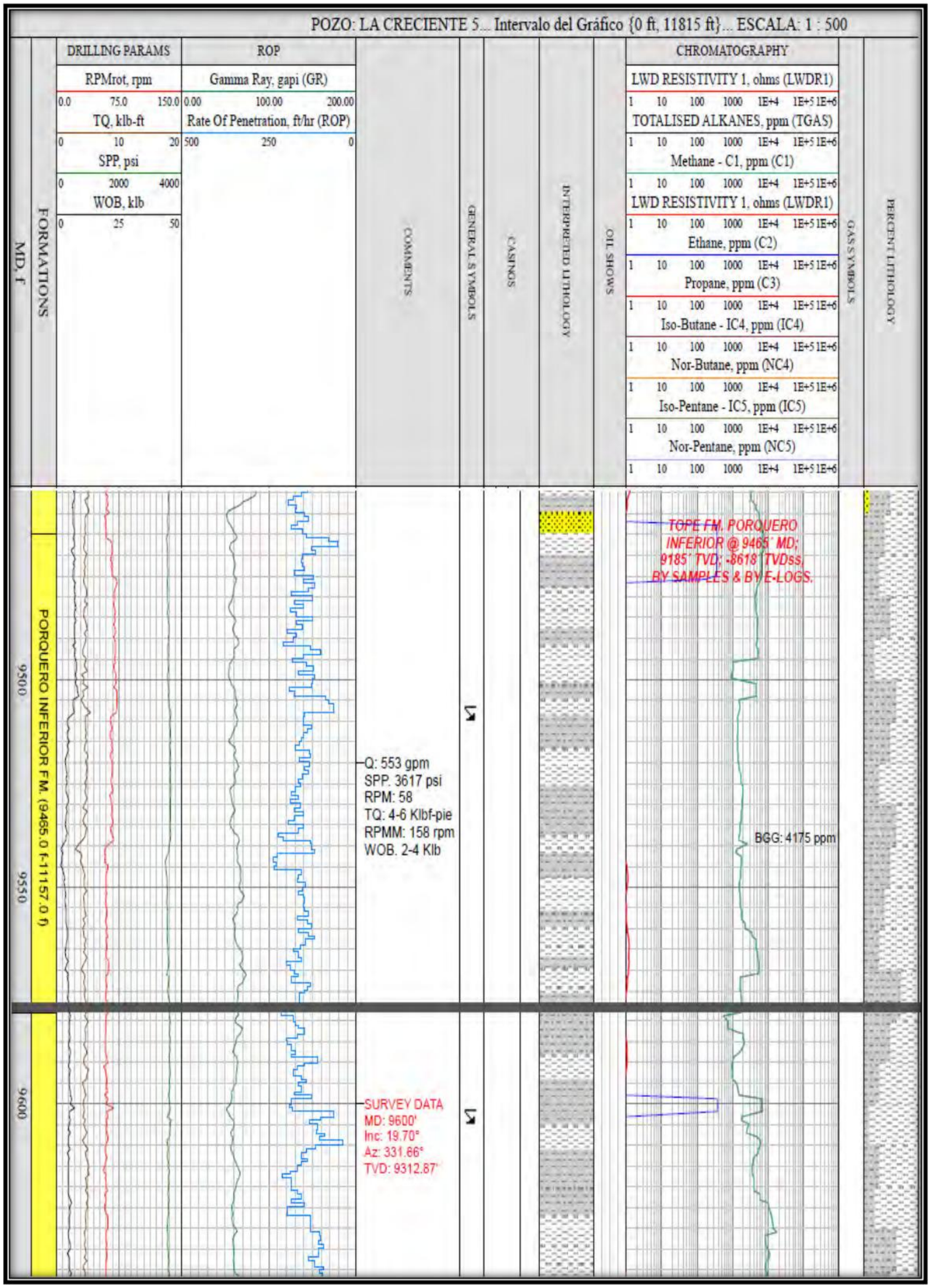
ÿ CLAYLITE. Medium to dark grey, occasionally medium grey; moderately firm, locally firm, sublaminar, less blotchy; silty; locally with a lutite appearance; occasionally calcareous.

ÿ SANDSTONE. Sublithic; medium greenish gray, medium gray; moderately consolidated, less friable; composed of 80% translucent white, hyaline quartz and 20% dark black and green lithic fragments, very fine grained, subrounded to subangular subspherical, good sorting; with siliceous cement, some with clayey matrix; poor visible porosity; with layers of carbonaceous organic matter; no visible manifestation of oil. Gradient to very fine-grained sandstone; locally clayey; locally with glauconite; not calcareous.

ÿ LIMOLITE. Medium to dark gray, less dark gray; moderately firm to firm, less firm; sublaminar, minor subblocosa, local blocosa; local.

ÿ MALLETITE. Medium to dark chalk, less dark grey, occasionally medium to dark greyish brown; firm, locally moderately firm; subbloc, less sublaminar, occasionally bloc, laminar and tabular; locally subfissile and subschist; locally clayey, occasionally silty; micropyritic; slightly calcareous.

Figure 31. Master log LCA-5 - Lower Porquero Formation



Source: LCA-5 master log provided by Pacific Rubiales

• Ciénaga de Oro Formation: It has a thickness of 558 feet. This formation is dominated by sandstones with limestone intercalations. The Gamma Ray log indicated an average reading value between 30 and 60 API, which correspond to sandstones. At 11,157 feet depth (MD) the first formation gas show of 5,381 ppm methane occurs, at 11,200 feet depth (MD) the second formation gas show of 6,470 ppm methane occurs, at 11,245 feet depth (MD) the third formation gas show of 17,080 ppm methane occurs and at 11,340 feet depth (MD) the fourth formation gas show of 18,861 ppm methane occurs, which indicates that the formation of interest is already in the formation due to the large formation gas show values and its progressive increase in ppm. At 11,190 feet depth (MD) the first background gas show of 6,640 ppm methane occurs and at 11,230 feet depth (MD) the second background gas show of 11,760 ppm methane occurs. Its top was found at 11,157 feet depth (MD) and its base at 11,715 feet depth (MD). In this interval, the following lithologies were identified through the analysis of trench samples, as shown in **Figure 32:**

ÿ CALCAREUS SANDSTONE (CALCARENITES). Sublithic; light grey to white, locally medium grey; friable, locally consolidated; blotchy; fine grained, to a lesser extent very fine.

ÿ SANDSTONE. Quartzy; very light brown to white; moderately friable; quartz grains, translucent, milky white, less very light brown

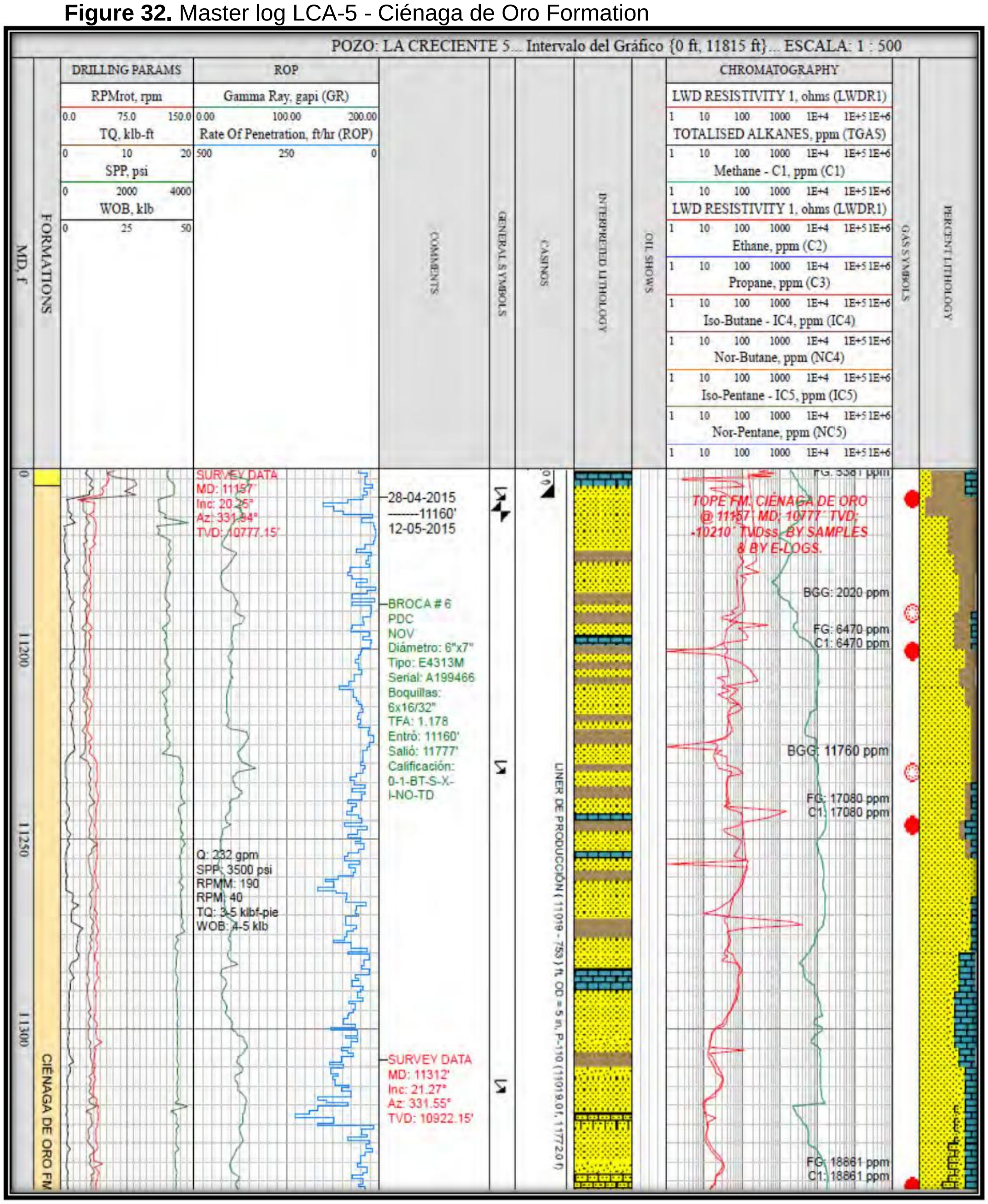
ÿ SANDSTONE. Sublithic; medium grey with white laminae, less light grey to white; friable, locally moderately consolidated; blotchy; quartz grains,

ÿ GLAUCONITIC LIMESTONE. Medium to light brown; soft; sub-bloc, less bloc; poor visible porosity; with abundant glauconite

ÿ LIMESTONE. Micrite texture, locally scattered micrite according to Folk, mudstone texture, locally wackstone according to Dunham; greyish white to white; soft; sub-bloc, lesser bloc; poor visible porosity; with dark laminations; locally with quartz grains; without visible manifestation of oil; fine to medium grain, locally coarse; sub-rounded, regular selection; locally calcareous clayey matrix, occasional siliceous cement; with abundant glauconite; without visible manifestation of oil.

ÿ MARL. Medium to dark gray, less medium brown; blocky to sub-blocky; soft to moderately firm; earthy texture; with organic matter, occasionally medium and coarse, sub-rounded, locally subangular, sub-spherical, regular selection; abundant calcareous cement, occasional clayey matrix; poor visible porosity; composed of 90% quartz and 10% dark lithic minerals; granular texture; with dark laminations; locally with glauconite; with limestone appearance sandy; no visible manifestation of oil, translucent, milky white, less medium grey and medium brown; fine grained, locally medium, occasionally coarse; subrounded, locally subangular, subspherical, regular sorting; calcareous cement (grey with white laminae), clayey matrix (medium grey to white); poor visible porosity; composed of 90% quartz and 10% dark lithic minerals; with dark carbonaceous laminations; locally with glauconite; no visible manifestation of oil.

Figure 32. Master log LCA-5 - Ciénaga de Oro Formation

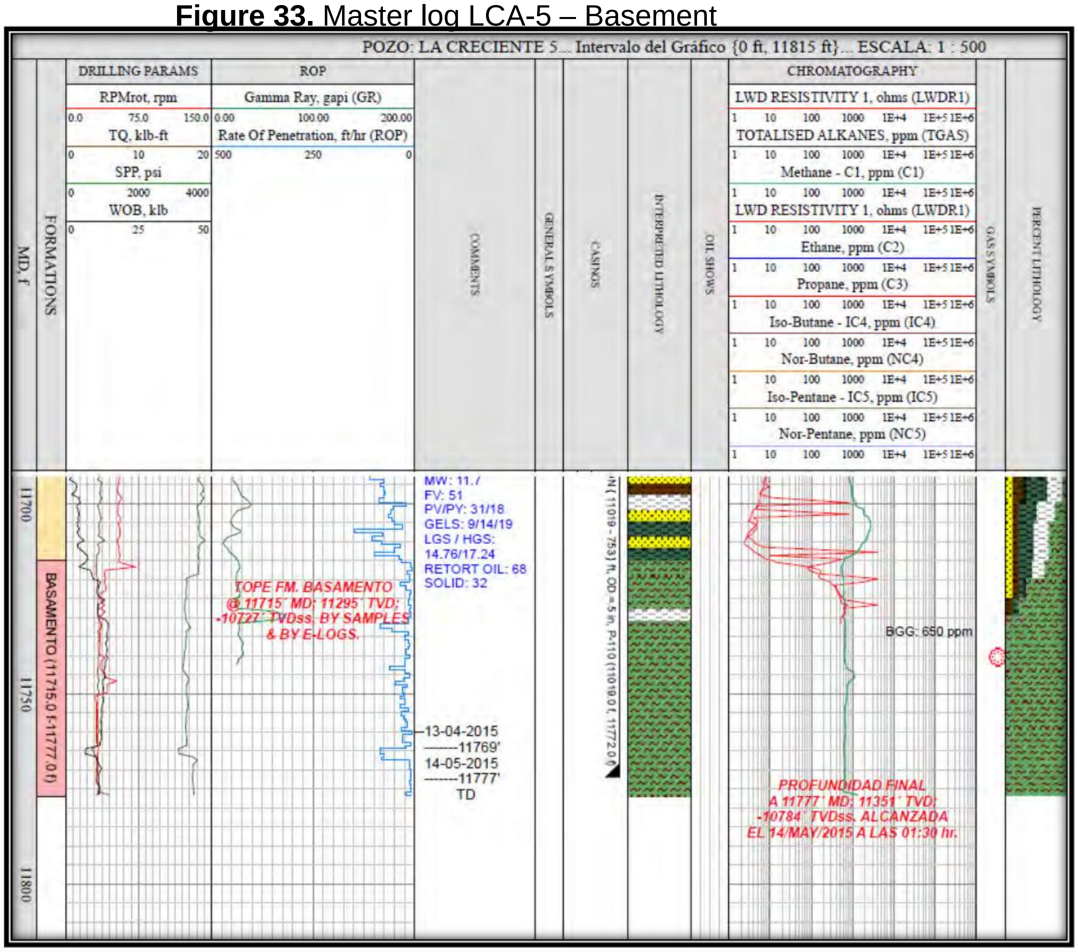


Source: LCA-5 master log provided by Pacific Rubiales

• Basement: The Gamma Ray log was run to 11,777 feet depth (MD), where it indicated a constant reading of 30 API corresponding to sandstones. By denoting the constant value of the Gamma Ray it is indicated that the basement was reached. At 11,735 feet depth (MD) a background gas show of 650 ppm of methane is presented. Its top was found at 11,715 feet depth (MD), in this interval the following lithologies were identified by the analysis of trench samples, as shown in **Figure 33:**

ÿ BASEMENT. Metamorphic rock fragments, predominantly Quartzite; dark to light green, white mottled with green, less milky white; very hard; blocky; crystalline texture; silica cement, welded; locally micropyritic; chalky appearance (milky white); occasional medium to coarse-sized quartz grain; angular; no visible porosity. occasionally with a clayey appearance: light green, olive green, occasionally grey, bluish grey; firm; sublaminar to subblocky; locally presents foliation with a slate and phyllite appearance.

Figure 33. Master log LCA-5 – Basement

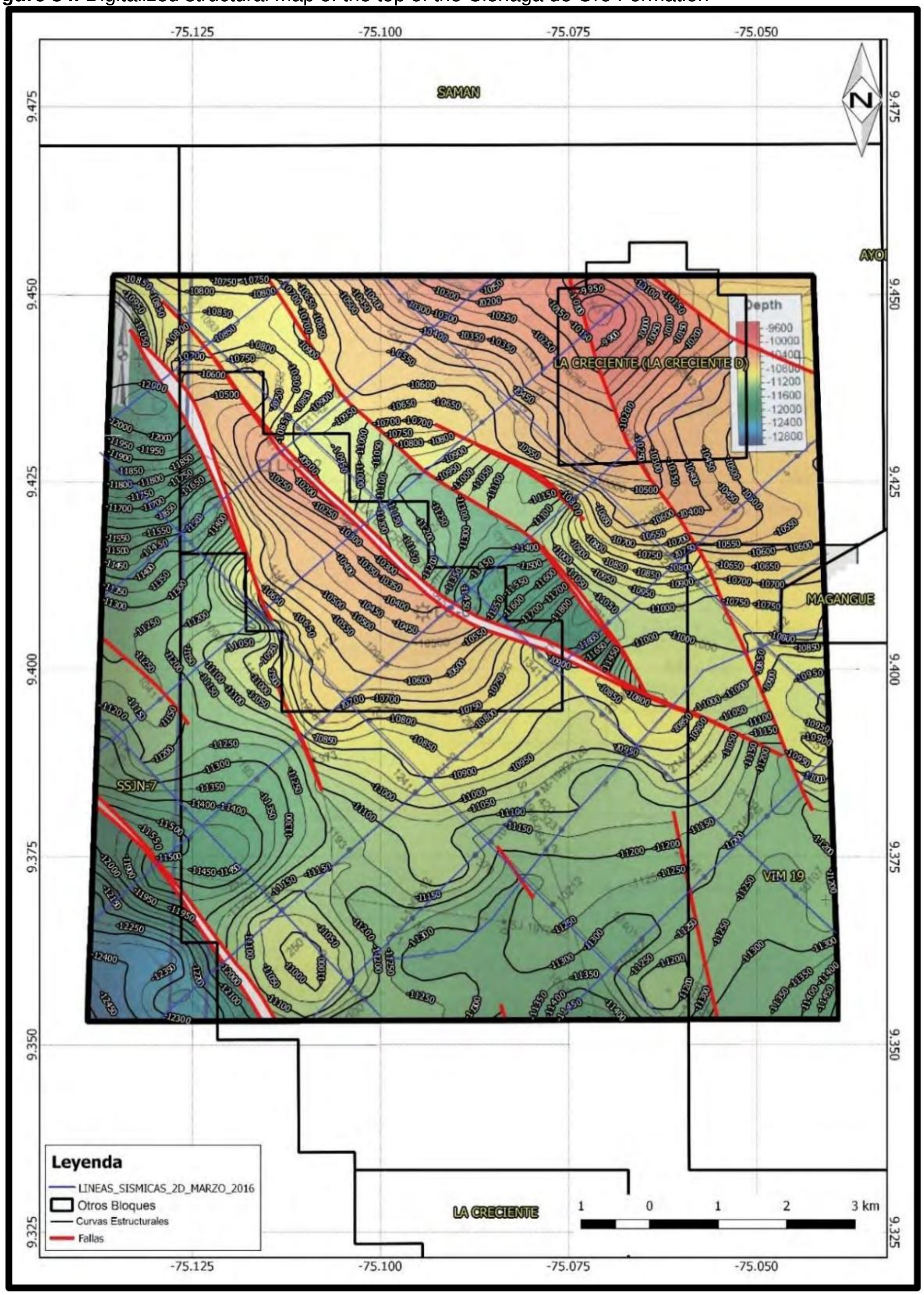


Source: Master log LCA-5 provided by Pacific Rubiales

2.3.3 Conclusion of conventional results. With the results of the conventional logs, a structural map was created at the top of the Ciénaga de Oro formation. It is noted that this map was delivered by the Pacific Rubiales company, which was modified and digitalized by the authors, as shown in Figure 34.

The red lines represent the faults causing all the strata movements in the area, the black lines represent the structural curves ranging from 9,500 to 12,500 feet, and the blue lines correspond to the seismic lines acquired in the area.

Figure 34. Digitalized structural map of the top of the Ciénaga de Oro Formation



Source: analysis of Pacific Rubiales seismic results, modified by the authors.

3. OIL AND GAS SEARCH TECHNOLOGY (OFT)

This chapter will describe the basic concepts of oil and gas exploration technology (OFT) and will also describe each phase, as well as the aspects that must be taken into account when carrying out any necessary data acquisition, the advantages of these acquisition methods and in turn the shortcomings that each method contains when carrying out an analysis and interpretation of possible hydrocarbon accumulations.

3.1 GENERALITIES

Oil and gas exploration technology (OFT) was born as a technology for military use due to the economic interest definitions of certain martial activities in the former Soviet Union.

Oil and gas technology (OFT) is a satellite technology in its first phase that allows direct prospecting of deposits for their development, based on the use of state-of-the-art tools such as satellites and electro resonance equipment in order to locate in greater detail the fluids present in the deposit; the technique of this technology is based on a study of the geoelectric parameters of the medium in the fields of transient geoelectric impulses and the quasi-stationary electric field of the Earth as well as the spectral characteristics of the deposits.

This technology allows:

- Calculate the volume of rock containing the hydrocarbon.
- Define the boundaries of oil-water contact
- Determine the optimal location for drilling wells
- Determine depth intervals for production intensification work Evaluate the depth and construction of vertical
- sections of “reservoir-like” distribution anomalies
- Identify and map areas of accumulation of hydrocarbons and other mineral resources Pre-evaluate reserves
-

The programs that will be used for effective localization during satellite spectrography and the following 2 phases are:

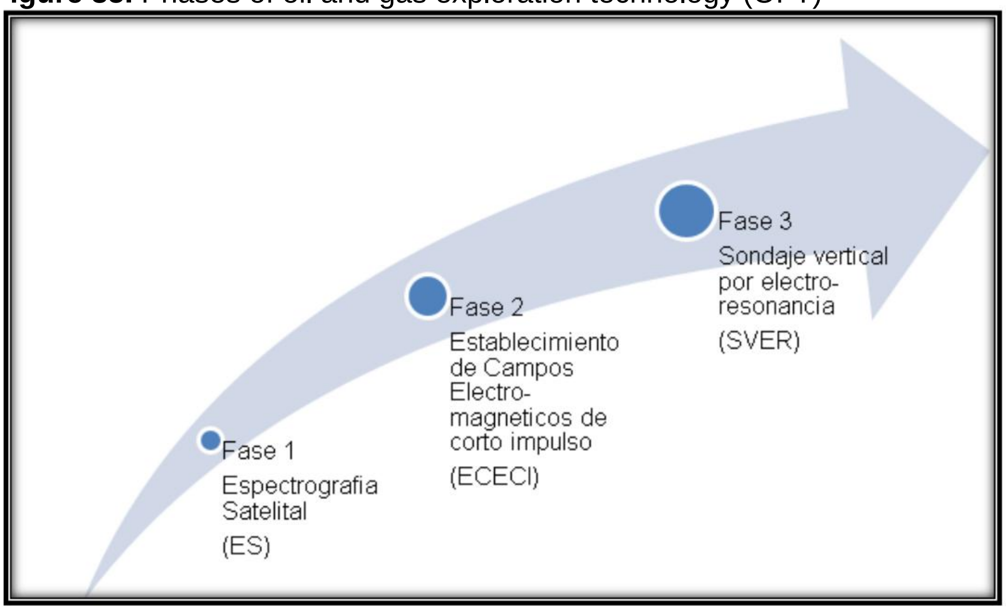
- ArcGis: allows you to perform functions that feed and manage a geographic information system, from map creation, information management and analysis, data and metadata editing.
- Basecamp: allows you to manage a calendar that allows coordination and management of projects.
- GPS trackmaker: allows you to create routes to follow using a GPS. • Mapsource: is responsible for transferring data from the GPS to the computer, allows you to save routes, transfer maps from the computer to the GPS. • QGis: allows you to explore data and create maps. • Surfer: a program responsible for processing spatial data, generating three-dimensional surfaces from various points.

The work of all these programs allows for the creation of the precise location of the area of interest, the access route and the processing of the metadata that will ultimately allow the digitization of the anomalies, defining what type of fluid they correspond to on a map.

3.2 PHASES OF OIL AND GAS SEARCH TECHNOLOGY (OFT)

Oil and gas exploration technology (OFT) is composed of 3 phases, as illustrated in **Figure 35.**

Figure 35. Phases of oil and gas exploration technology (OFT)



- The first phase is of a satellite nature, allowing to delimit in the first instance the areas of interest represented on a spectrography map.
- The second phase is carried out from the results of the first phase, since knowing the area will make the most detailed study which will deliver as

The result is a thickness map delimiting in more detail the area where the fluids of interest are located.

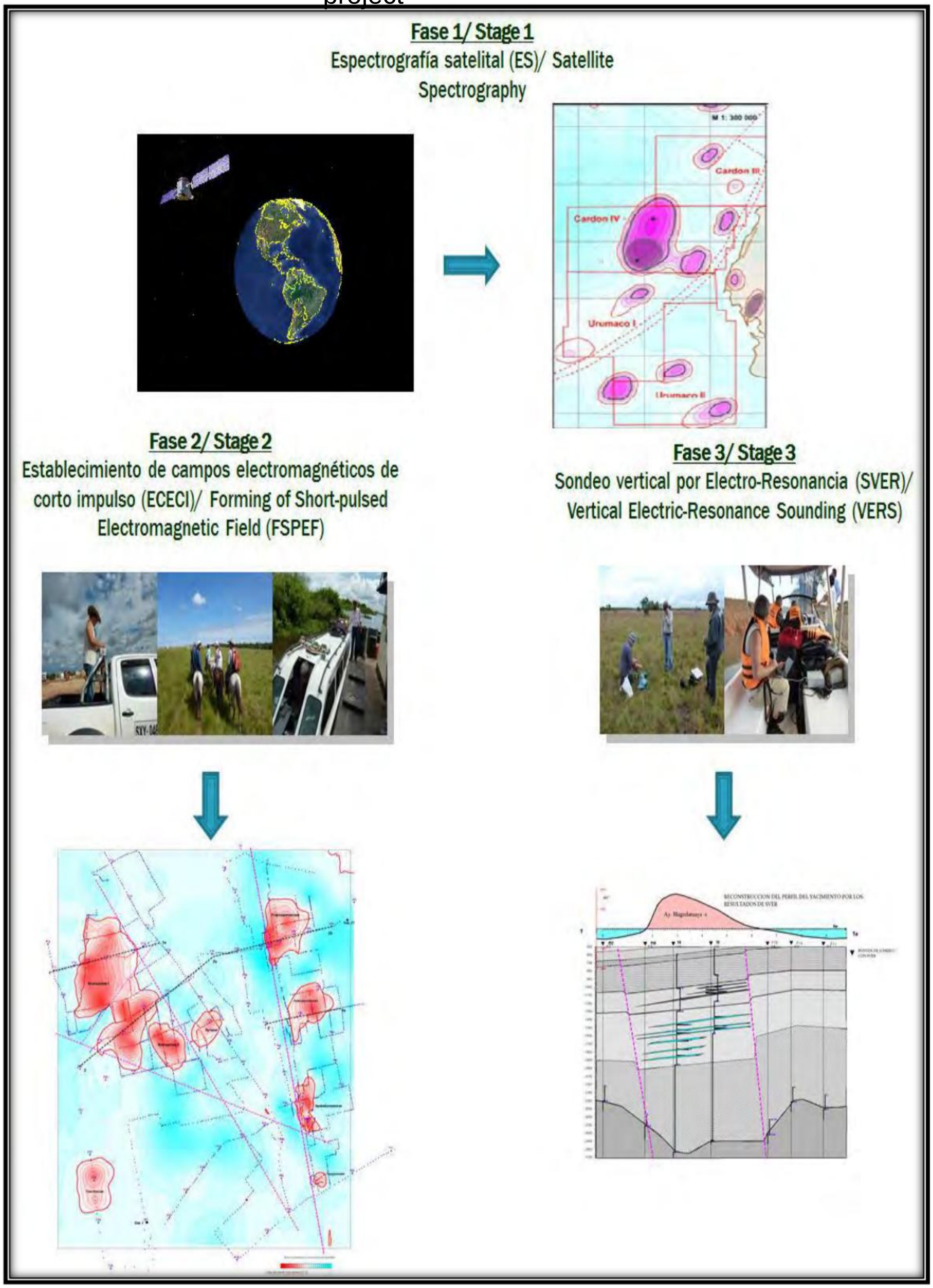
- The third phase is then carried out using the results of the previous phases, which allows defining the depth at which the fluids of interest are located, presenting their corresponding thicknesses.

The sum of these three phases allows us to deliver as a final result a profile of the area showing an estimate of how the fluids of interest are deposited, at the depth in the corresponding strata.

The first phase is a remote method that is carried out using satellites that are in a certain network in space. The other two phases are executed based on the results of the first phase, since the field work is carried out in the areas of greatest interest in order to proceed to implement high-tech tools to carry out a more detailed analysis, delimiting the presence and location in depth of the fluids present in said areas.

Figure **36** presents a graphical description of an oil and gas exploration technology (OFT) project in the acquisition of its 3 phases, showing an example of the previously processed results.

Figure 36. Oil and gas exploration technology (OFT) acquisition and prospecting project

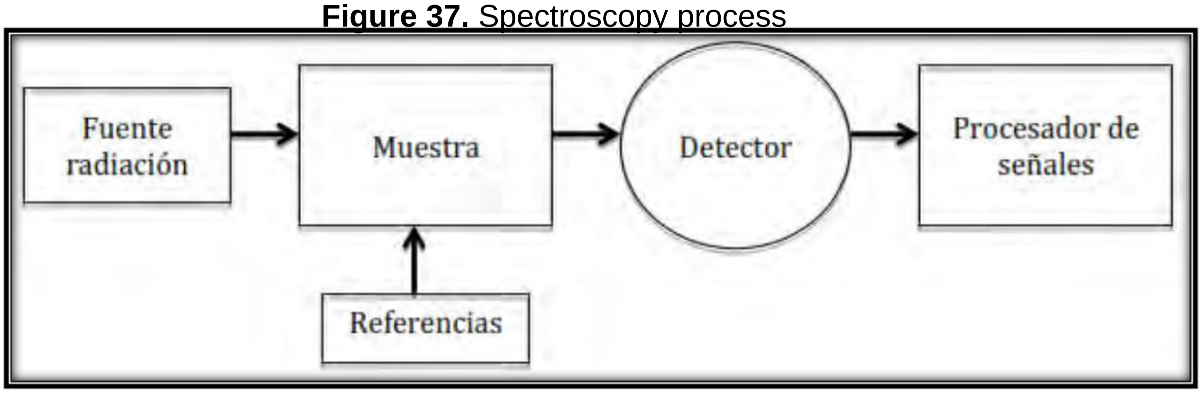


Source: Advanced Technologies Company of COLOMBIA, OFT Technology, 2015.

3.2.1 Phase 1: Satellite spectrography (ES). Satellite spectrography consists specifically of the study of light previously broken down into monochromatic radiation by means of a prism or a diffraction grating. In order to understand it clearly, it is necessary to first define spectroscopy, which is the study of the interaction between electromagnetic radiation and matter, with absorption or emission of radiant energy.

Figure **37** shows the process of a spectroscopy:

Figure 37. Spectroscopy process

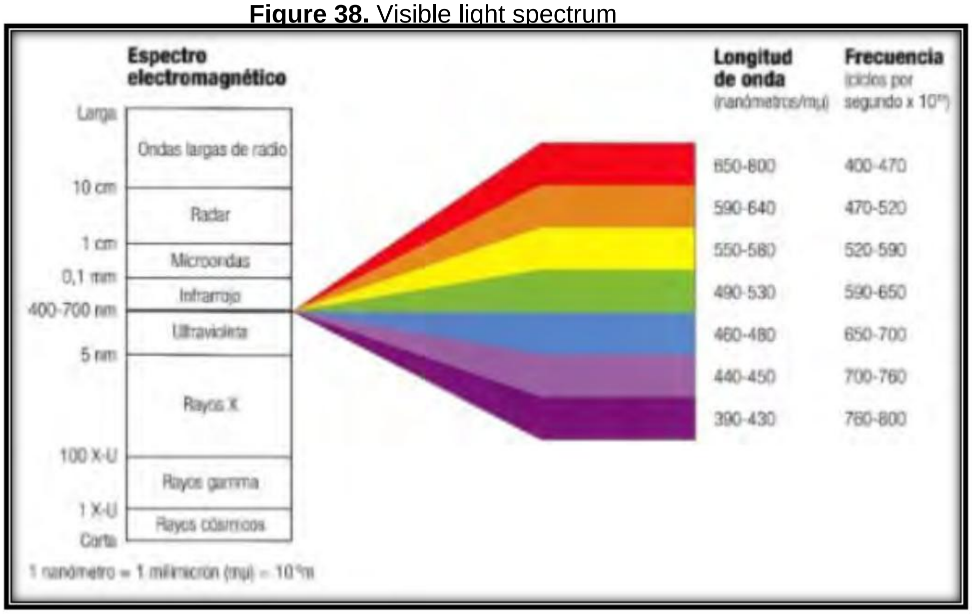


Source: Pirson SJ Prediction of hydrocarbons in place by magnetoelectrotelluric exploration// Oil and gas. J. – 1976 – 74, No. 22

Spectrometry is used for the identification of gas, among other fluids, in this case it is identified by measuring the frequency of the ray absorbed by the formation or layer of earth in the area of interest, knowing that each mineral or fluid has a frequency corresponding to the response of the wave excitation.

Figure **38** describes the electromagnetic spectra with their respective length and frequency:

Figure 38. Visible light spectrum



Source: University Physics – Sears – Zemansky – 12th Edition – Vol2 – Chap. 32

In order to better understand the relationship between the emission of the light ray and the earth, the concept of the Pirson model must be clear.

Distribution of ions in the PIRSON model atmosphere:

The Earth has an electromagnetic balance with the environment that surrounds it; when it comes to altering this balance in one way or another, it is about compensating for normality; a clear example is the electric rays that are emitted in the storm and fall to the Earth to compensate for this alteration and return to balance.

When lightning is emitted to the ground, in any subsoil deposit, a polarization of the rocks adjacent to it is generated, that is, a redistribution of electrical charges which in turn causes a potential difference (electrical currents of up to 100 mA per acre in a good climate or under a thunderstorm can reach a value of up to 20,000 mA per acre).

An accumulation of electrical charges is then established on the deposits that are compensating for the accumulation of charges in the subsoil, which within the oil and gas search technology (OFT) are called electromagnetic anomalies, which show on the surface the existence of hydrocarbon deposits in this area of the subsoil.

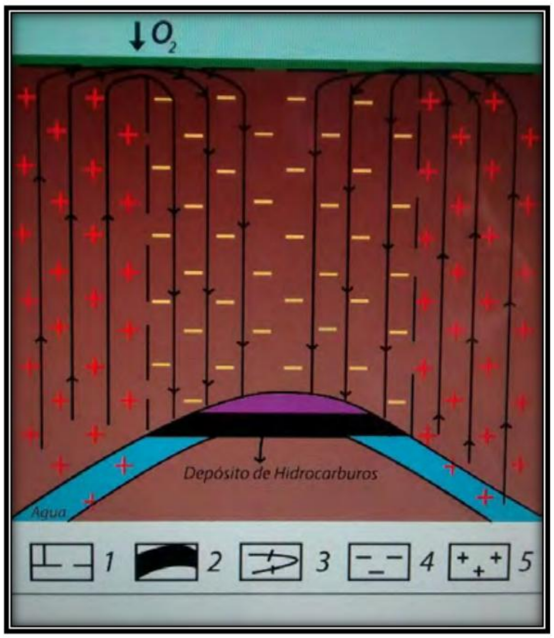
Atmospheric anomalies due to the presence of hydrocarbon deposits can be observed indirectly using multi-spectral spectroscopy such as that used by atmospheric observation satellites.

By measuring the intensity and distribution of atmospheric anomalies related to hydrocarbon deposits, it is possible to establish the regions most likely to contain hydrocarbon deposits.

According to PIRSON, a reduction environment with an excess of electrons is created above the gas-crude deposit, and around and below it an oxidation environment with a deficit of electrons is created, resulting in a potential difference and an electric current appearing in the chain.27

In **Figure 39,** the above is represented where 1 is the oxygen saturation line (surface of the upper limit of the aquifer); 2 is the hydrocarbon (HC) reservoir; 3 are the stream lines (the arrow indicates the direction of the stream); 4 is the electron excess zone (reduction environment) and 5 is the electron deficit zone (oxidation environment).

Figure 39. Accumulation of electrical charges on the Earth's surface



Source: "Fuel element" diagram modified by the authors28

What is done in the satellite spectrography phase is to emit a beam from the satellite at a given frequency that allows momentarily altering the electromagnetic balance of the earth in the area of interest, and then map it.

---

[27] VN Shuman, SP Levashov, Drilling Systems: Elements of Theory, Current State and perspectives Article from the publication Geoinformatics 2-2008 .

[28] VN Shuman, SP Levashov, Drilling Systems: Elements of Theory, Current State and perspectives.,Article from the publication Geoinformatics 2-2008,

the areas where frequencies matching the emitted search frequency are recorded.

It should be noted that the values of the frequencies emitted for each fluid are completely confidential because it is one of the principles of oil and gas search technology (OFT).

In order to determine the frequency at which each fluid responds, several studies and laboratory tests were carried out, concluding that free gas can be identified through a specific frequency that is assumed to be standard (because it is obtained under controlled conditions in the laboratory), and which is used to scan the area studied and thus identify electromagnetic evidence of gas represented as deposits of DAT-type anomalies “gas type”.

It was experimentally determined that when the gas pressure was varied under laboratory conditions, the frequency recorded a phase shift directly proportional to the variation in pressure, which allows the anomalies to be represented in pressure units.

The oil and water frequencies were also determined to scan the satellite material (the metadata). By emitting the wave in these areas with accumulated charges on the surface, according to the PIRSON model, they are compensating for the charges inside the subsoil where the hydrocarbon deposits are located.

The information obtained is of the original spectral type, in which the intensity of the electromagnetic field is recorded in five frequency bands ranging from ultraviolet to infrared, which are referred to within oil and gas exploration technology (OFT) as metadata.

This metadata is processed in the Geophysics Laboratory in kyiv or Moscow by scientists using specialized software to obtain the spectrography of the areas of interest, which are represented by an isopach map detailing the anomalies.

The results of the electromagnetic evidence are obtained in pressure units (Mpa and Psi), referred to within oil and gas exploration technology (OFT) as relative formation pressure, since experience has shown that it is closer to formation pressures and not to hydrostatic pressures, which in turn serves as a parameter to judge the prospectivity of the identified area.

In this first phase we can have an idea of the size of the deposits and which would be the best prospect by formation pressure vs hydrostatic pressure.

Hydrostatic pressure is directly proportional to depth, corresponding to 1 Mpa at 100 meters (1 Mpa = 145 psi).

With this pressure data, assuming the above equality, the estimated depth can be correlated with the depth range of the reservoir formations from the geological studies, allowing the location of the prospective fluid area of interest to be validated, since for each area the depth range of the producing formations, reservoirs, etc. are known from studies. The acquisition of satellite information is carried out from a network of specialized geophysical satellites with passive platform sensors operated by the Russian space agency called GEORESURS.

The Resurs-P satellites were designed for remote sensing of the Earth's surface in order to obtain highly informative images of the visible spectrum on a time scale close to real time. The high-resolution optical-electronic equipment is complemented by the Hyperspectral Imaging Acquisition System (SAIH) and the large-scale acquisition complex for high-resolution multispectral images (CAIM-AR) and medium-resolution images (CAIM-RM).

The “Resurs-P” satellite No. 2 was launched in 2014 and the “Resurs-P” No. 3 was launched in 2015. Since the average life of a satellite is 3 years, that is why satellites are being changed to improve the efficiency of the Russian network.

3.2.2 Phase 2: Establishment of short-impulse electromagnetic fields (SEMF). The SEMF method consists of the process of emitting an electromagnetic signal through a generator at certain specific frequencies, which momentarily alter the anomaly, generating an electric current in the receiving antenna.

Figure **40** corresponds to the generator used by oil and gas exploration technology (OFT).

Figure 40. Wave generator

Source: Advanced Technologies Company of COLOMBIA, OFT Technology, 2015.

The temporal characteristics of this process of excitation of the signal and its subsequent attenuation depend on the state of the surrounding medium in the near-surface space of the Earth. The time of establishment of the field and the characteristic of the signal attenuation are in direct relation to the density of the atmospheric charge in the layer adjacent to the Earth's surface and the sign of its charge.

The amplitude and the recovery or attenuation time of the resulting wave depend on the amount of hydrocarbons detected at that point.

Figure **41** depicts a beam receiving antenna used by oil and gas exploration technology (OFT).

Figure 41. Receiving antennas

Source: Advanced Technologies Company of COLOMBIA, OFT Technology, 2015.

Depending on the sign of the polarization of the objects on the polarizing objects, zones with positive or negative ionization are formed, which are fixed with the establishment signals since this effect is used to map the zones with different signs of polarization of the layers allowing the anomalies to be shown.

For recording hydrocarbon deposits, stable equipment was created against interference, of reasonable size and weight, based on the use of short wave excitation pulses and the recording of the establishment processes in small "vertical dipole" type ferrite antennas.

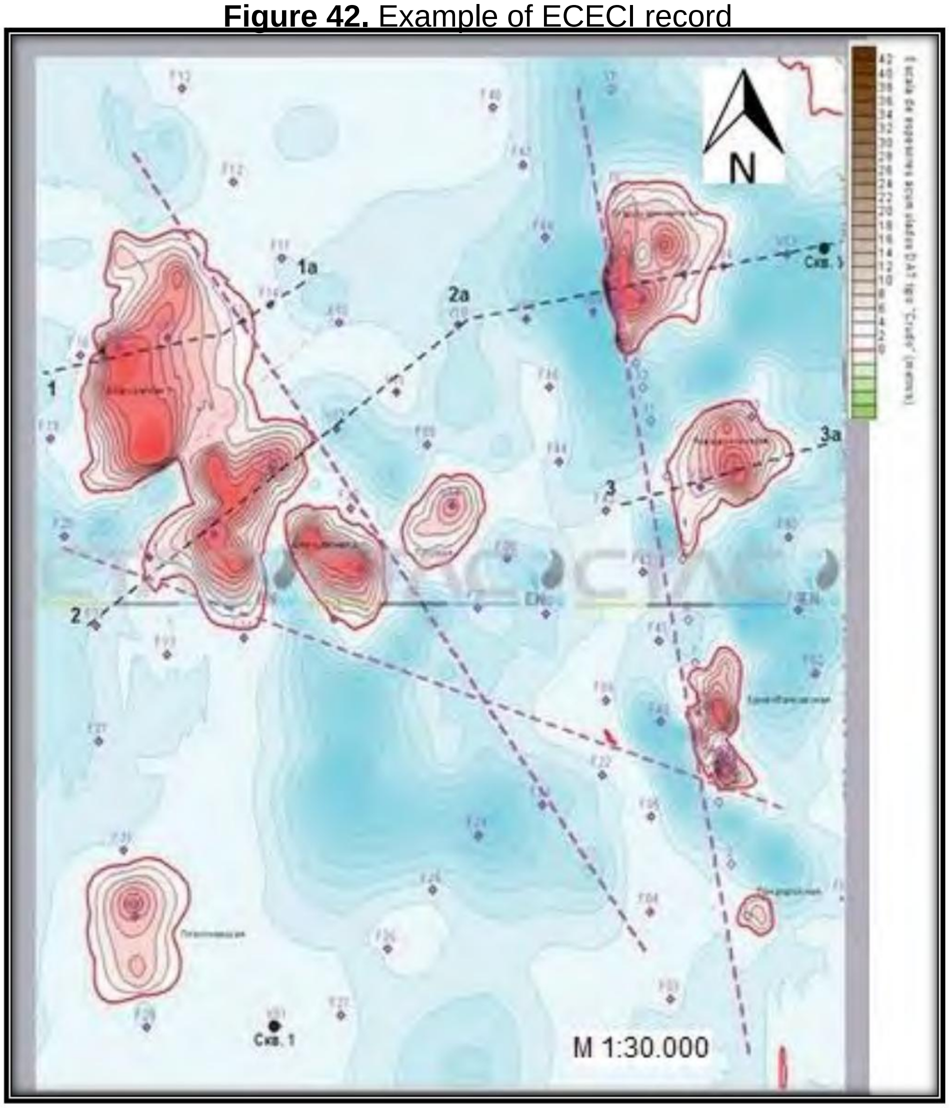
In the equipment modified for the application of ECECI, a short electromagnetic pulse of 10 microseconds duration is used to generate the signal (The excitation current is 10A). The generating antenna with a small active and inductive resistance is built in the shape of a broken ring.

The encoded signal is written and recorded on the computer's hard drive and at the same time with the recording, the first phase of the initial information processing is done on the field computer monitor; to delimit the hydrocarbon deposit, the summation of the signals in a certain time interval is done.

The objective of the ECECI is to delimit more precisely the anomalous zones detected by spectrography, thus defining their geometry to dimensions relatively close to the real shape of the reservoir and the areas of greatest concentration of accumulated thicknesses with hydrocarbon.

Figure **42** is an example of an ECECI record.

Figure 42. Example of ECECI record



Source: Advanced Technologies Company of COLOMBIA, OFT Technology, 2015.

3.2.3 Phase 3: Vertical Electro-Resonance Sounding (VESS). This is based on the study of the spectral characteristics of the neutral electromagnetic field that forms over oil and gas deposits.

The layer above the crystalline basement contains a series of sedimentary layers that differ from each other not only by the type of rock and its chemistry but also by their electromagnetic properties. This gives rise to the so-called polarized dipole systems, that is, each layer has a differential electrical potential.

The Vertical Electro-Resonance Sounding (VES) method consists of identifying in depth the different polarized layers caused by hydrocarbon deposits and recording the response of these layers to the excitation that is made on the surface with an electromagnetic signal that destabilizes the Earth's electric field with a 10 microsecond signal.

By artificially varying the magnitude of the Earth's electric field, the different layers inside the subsoil respond with electromagnetic waves that attempt to reestablish the balance of the electric field to its initial value.

Since the excitation is done with the specific frequency of the fluids (oil, gas, water) only the rocks that contain these fluids emit these response waves.

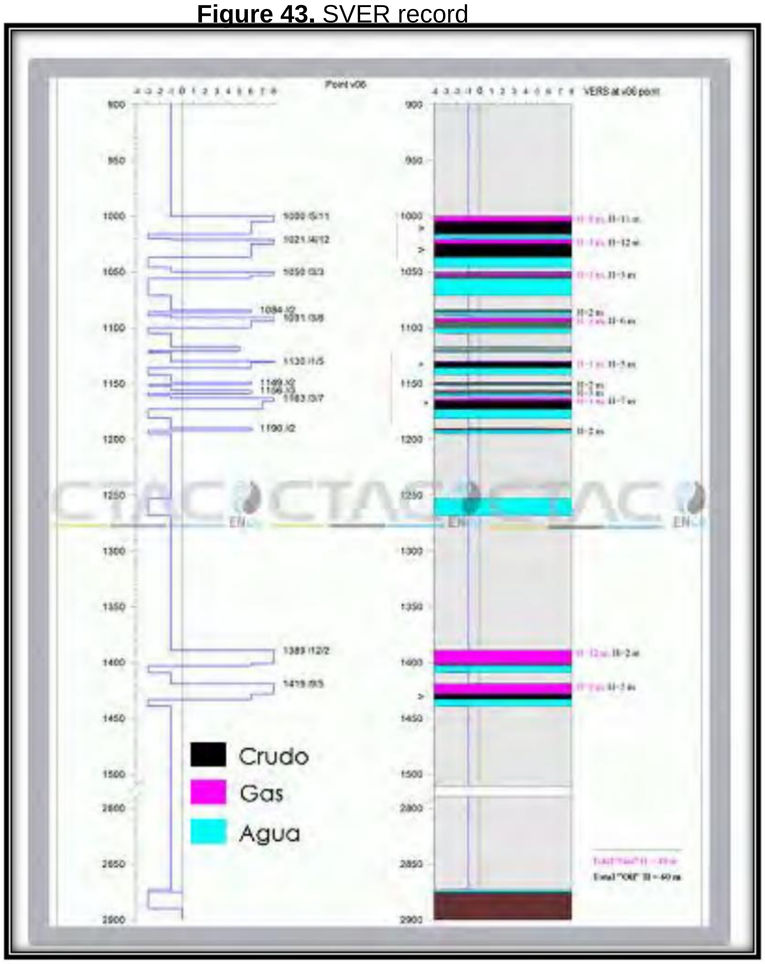
These restoring response waves are captured on the surface with SVER equipment and analysed with special software developed by the OFT scientific team, which ultimately allows the depths of origin to be determined, as well as the quantity of rock intervals with hydrocarbons, depths and their thicknesses.

By projecting a series of SVER points across the anomalies and interpolating the results, profiles or sections can be constructed that show the distribution of the target fluids at depth (oil, gas, water).

The objective of the Vertical Electroresonance Survey (VES) is to define the depth and thickness of the intervals of interest, which are the direct generators of the anomalies projected in phase 1 and 2; in addition to the creation of vertical profiles of each detected anomaly. Each fluid has a respective voltage difference value which allows to clearly differentiate its presence in the well.

Figure **43** is an example of a SVER record.

Figure 43. SVER record



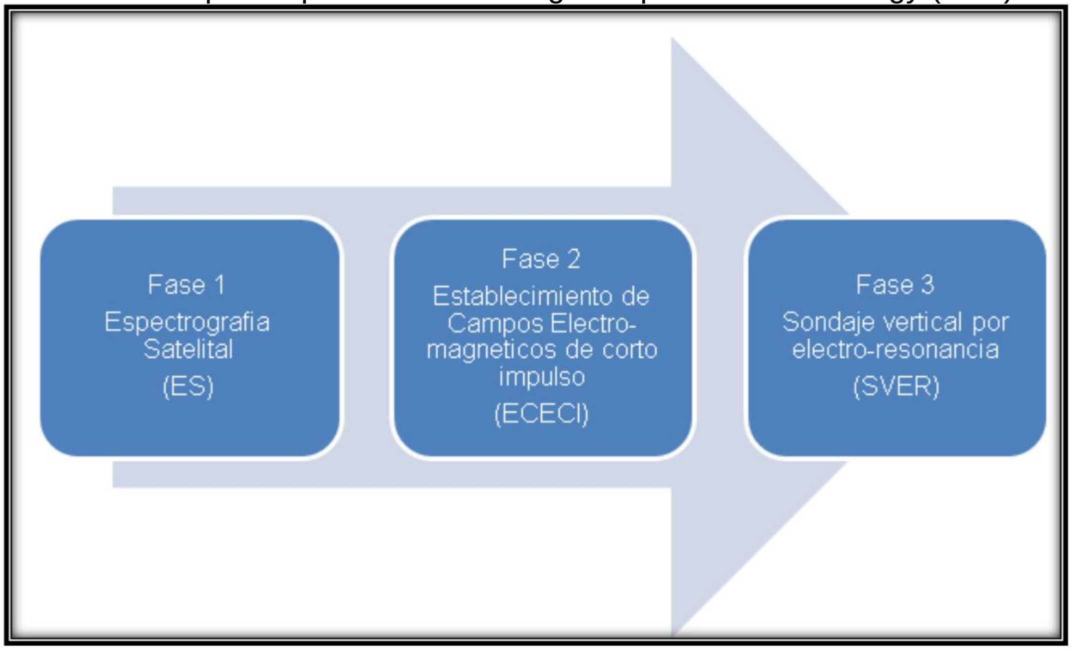
Source: Advanced Technologies Company of COLOMBIA, OFT Technology, 2015.

3.3 DEVELOPMENT PHASES OF OIL AND GAS SEARCH TECHNOLOGY (OFT)

The development phases of the oil and gas search technology (OFT) are based on three stages of execution. The achievement of these three stages allows for a complete prospecting of the identification of electromagnetic anomalies originating from hydrocarbon deposits, determining the location of areas with the presence of fluids, in addition to an identification of pressures and thicknesses. Finally, a comparison of the data collection points is carried out and profiles of the area of interest are made, indicating with prospective depth the location of the fluids of interest.

Figure **44** depicts how oil and gas exploration technology (OFT) is developing.

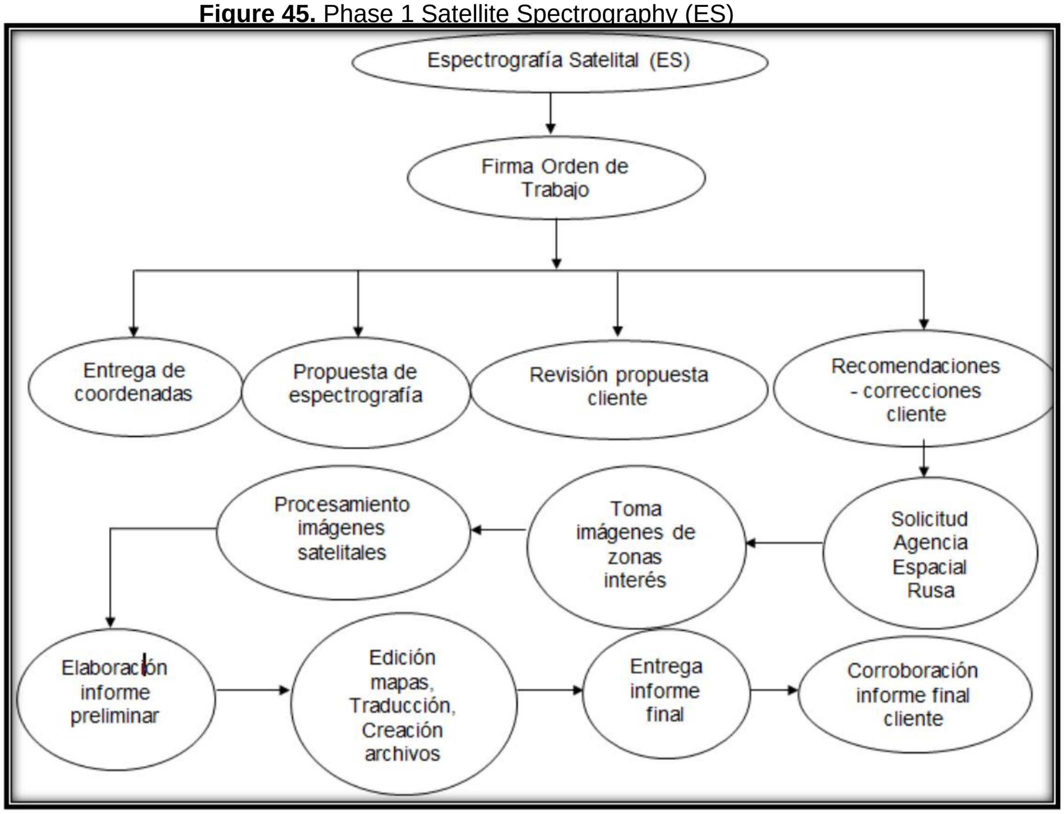
Figure 44. Development phases of oil and gas exploration technology (OFT).



3.3.1 Phase 1 design: Satellite spectrography (ES). For the initial phase of satellite spectrography in the development of oil and gas exploration technology (OFT), an area of interest is determined over which the resonance frequency analysis process will be run from the satellite part provided by the field operator (PACIFIC RUBIALES). For the present study, the area of the La Creciente block in the Lower Magdalena Valley Basin was delimited.

Phase one 1 consists of the methodology reflected in Figure **45.**

Figure 45. Phase 1 Satellite Spectrography (ES)



Once the work order has been completed and the coordinates of the satellite data collection site have been established by the operator, and if necessary, according to the proposal made by the operator, it is recommended to change the collection points if necessary or to consider necessary areas that are complementary to the prospecting of the area. These points are reviewed and compared by the working group of Russian technicians and those in charge of identifying the anomalies in the area.

After verifying the data collection points and areas, a request for a quota is made to the Russian Space Agency. From the point where authorization is received from the Agency, images are taken over the area of interest. In this case, they will be taken over an area of 89 km2 of the La Creciente block, Lower Magdalena Valley basin.

It is important to remember that for the development of this technology the operating company did not provide information on existing wells, well status, stratigraphic columns of fields and/or lithological descriptions, depths and tops of the formations, structural maps, locations, geometries, and areas of structures both prospective and producing, faults and their orientation, well production, reserves, resources and basement depth. Therefore, in these stages the entire results structure was designed with information minimum, in future chapters this information obtained is compared with the information existing in the area using conventional methods.

For Phase 1 of satellite spectrography, it was necessary to have specialized technical personnel, this team is made up of:

• 2 electronics specialists • 2 geophysicists • 1 geologist

Figure **46** corresponds to the equipment required in Phase 1 of satellite spectrography.

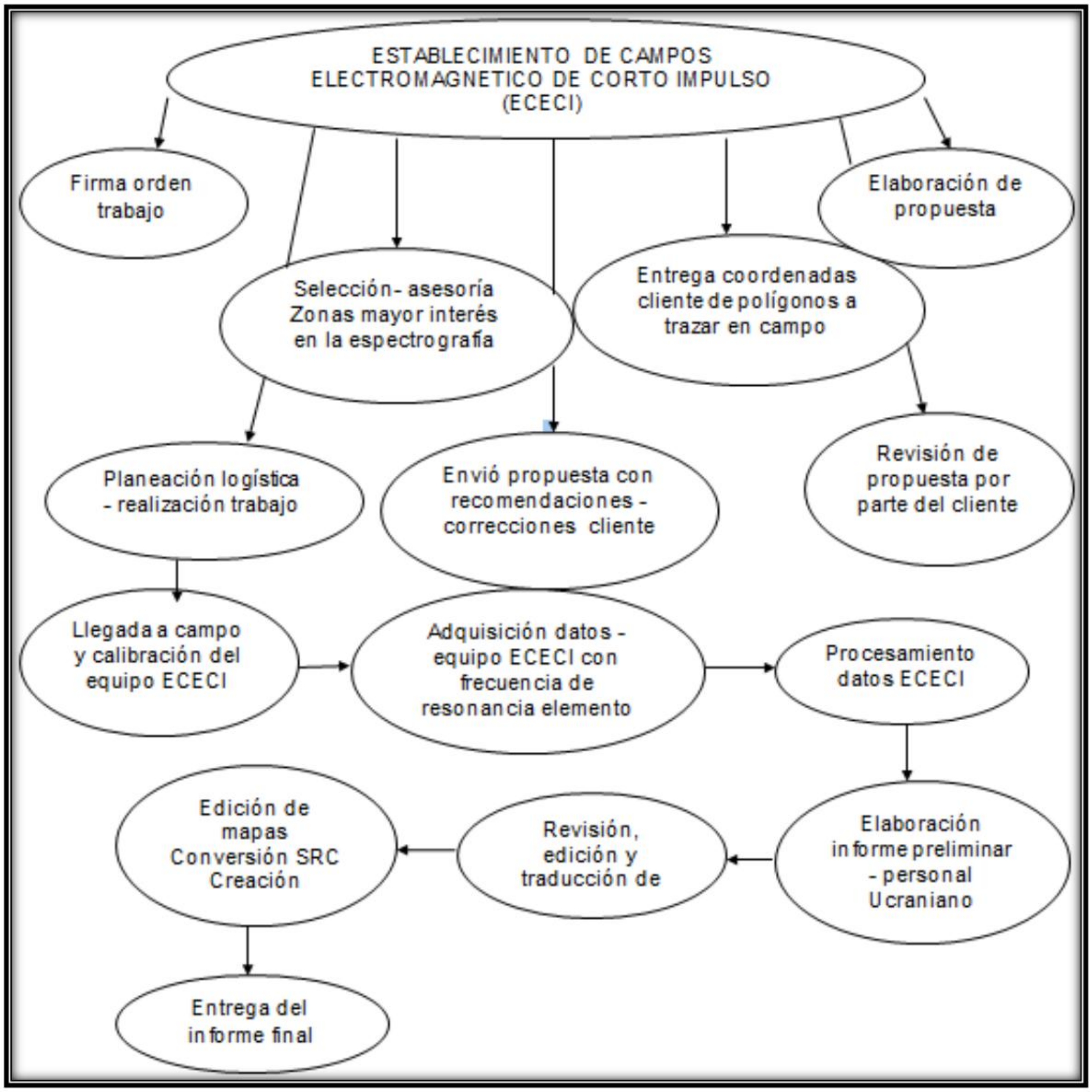
Figure 46. Processing Laboratory Phase 1 Satellite Spectrography

Source: Advanced Technologies Company of COLOMBIA, OFT Technology, 2015.

The support of this work team allows for the processing and interpretation of data.

3.3.2 Phase 2 design: Establishment of short impulse electromagnetic fields (ECECI). For the execution of the second phase, in the La Creciente Cuenca field in the lower Magdalena Valley, measurement zones will be determined within the initial polygon. A study will be run at this stage which begins to focus on the areas that indicated the greatest potential in phase 1, remembering that the establishment of electromagnetic fields is to generate and attenuate electromagnetic signals generated by equipment and received by a series of receiving antennas. Before this, schematically, phase 2 of the OFT technology, as shown in the methodology in Figure 47:

Figure 47. Phase 2 establishment of short impulse electromagnetic fields (SEE)



In all phases it is necessary to carry out the work signature, after this with the unidentified areas, in the phase we proceed to standardize the data that present greater relevance, advising the operator on which anomalies are desired to be characterized, this is why within the process the operator must again generate new coordinates within the initial agreed area (89 km2), these new areas will be taken, analyzed and if necessary, concepts of recommendations of these points will be generated or if other points should be taken into account.

Following this, the logistics are organized since this second phase corresponds to data collection in the area of interest, therefore, it is necessary to move all the equipment of instruments and technicians necessary for its execution.

Specialized technical personnel:

For the second phase, it is necessary to have 3 ECECI equipment operators, geophysicists trained to handle the equipment (special Russian equipment), as illustrated in **Figure 48.**

After having the necessary equipment and personnel, the equipment is calibrated in the field and in turn the access permit to the land chosen for the execution of these is processed, taking into account that the oil and gas search technology (OFT), does not require an environmental license and the impact on the environment that it generates is minimal since the personnel and the work equipment are transported in a single vehicle and in terms of the affectation of private lands where the anomalies were identified, there are no affectations such as earth movement or felling of flora in large quantities, land occupations for long periods of time, the established vehicle simply enters the land and the data is taken as seen in Figure **48.**

Figure 48. Assembly and mobilization of Phase 2 ECECI equipment

Source: Advanced Technologies Company of COLOMBIA, OFT Technology, 2015.

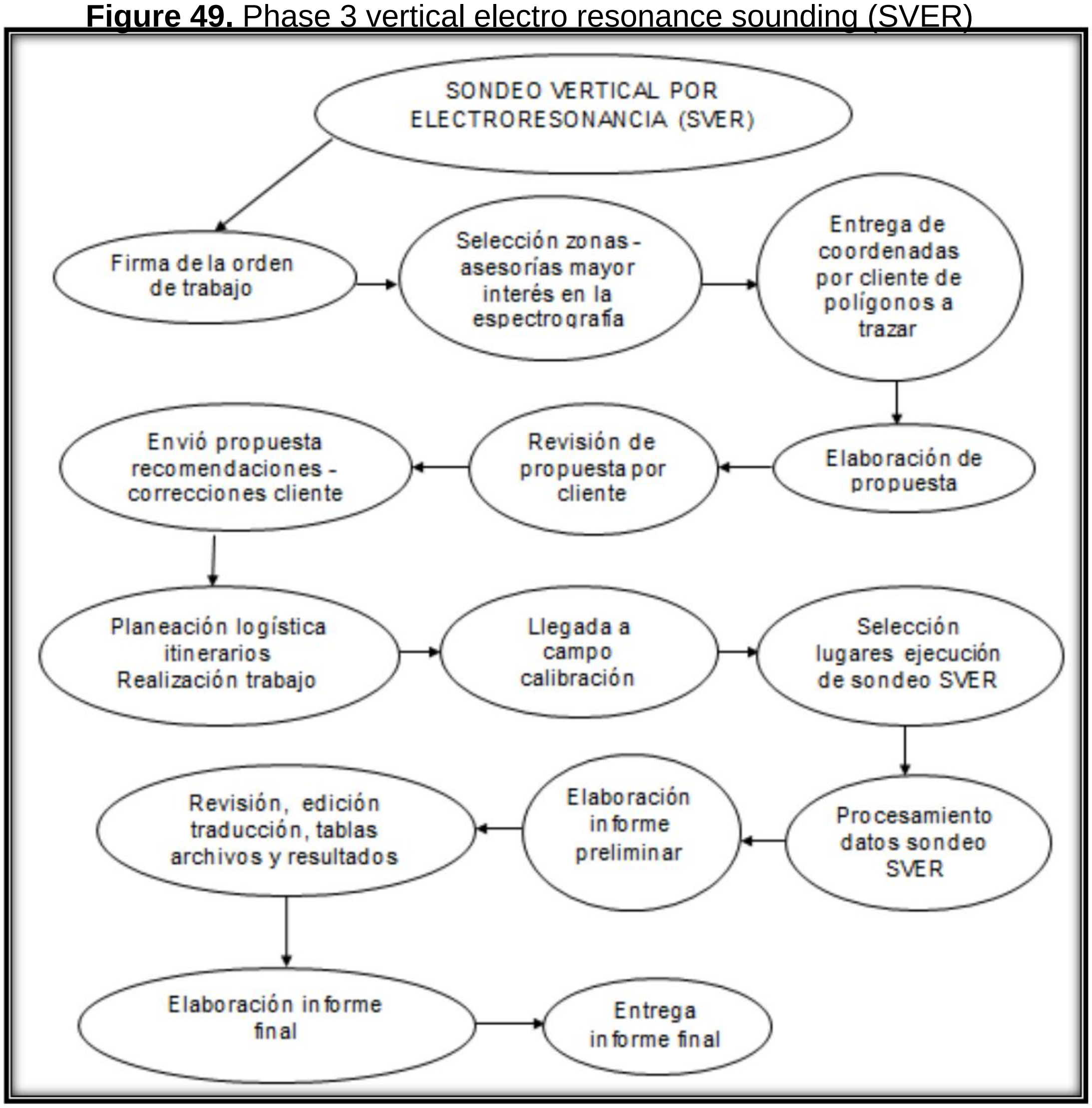
Depending on the areas in which the points where the ECECI data will be taken were chosen, for the La Creciente Field area in the Lower Magdalena Valley Basin, important and considerable prospective areas will be defined.

The acquisition of data in the field area was determined by the points where the transport vehicle allowed traffic, and on several occasions the points were taken by the work team on foot. After taking the corresponding data in these areas, the work team analyzes the data.

for a certain period of time and are sent from Russia for further analysis and determination to continue with the study.

3.3.3 Phase 3 design: Vertical electro resonance sounding (SVER). For the third phase, the study of the spectral characteristics of the natural electromagnetic field allows determining the oil and gas deposits, added to the principles of polarization, the following work plan is available as illustrated in Figure 49.

Figure 49. Phase 3 vertical electro resonance sounding (SVER)



In the development of the final phase of oil and gas exploration technology (OFT), corresponding to phase 3 of vertical electro resonance sounding (SVER), the process to be carried out according to the work schedule established above, is to choose points of greatest interest shown in the spectrography to carry out surveys based on the study of the natural processes of average polarization and the spectral characteristics of the natural electric field over a deposit.

The equipment required for the development of this phase does not require the installation of long lines or cables and is characterized by low energy consumption, as well as the use of operators is very low.

After having this, we proceed to organize the logistics since this second phase corresponds to data collection in the area of interest, therefore, it is necessary to move all the equipment of instruments and technicians necessary for the execution of the third phase.

Specialized technical personnel:

For the third phase it is necessary to have 3 SVER equipment operators, geophysicists trained to handle the equipment (special Russian equipment), as illustrated in **Figure 50 and Figure 51.**

After having the necessary equipment and personnel, the calibration of the equipment in the field is carried out and in turn the access permit to the land chosen for the execution of these is processed, taking into account that the oil and gas search technology (OFT), does not require an environmental license and the impact on the environment that it generates is minimal since the personnel and the work equipment are easy to mobilize as well as phase 2 ECECI, there are no impacts such as earth movement or felling of flora in large quantities, land occupations for long periods of time, the established vehicle is simply entered into the land and the data is taken as seen in **Figure 50**

and Figure 51.

Figure 50. Field tool laying process Phase 3 SVER

Source: Advanced Technologies Company of COLOMBIA, OFT Technology, 2015.

Figure 51. SVER Phase 3 Equipment

Source: Advanced Technologies Company of COLOMBIA, OFT Technology, 2015.

Once the 3 phases of the oil and gas search technology (OFT) are completed, it will take 1 month for processing and delivery of results which will indicate the areas where hydrocarbons are present with their respective location and stratum size which will allow a calculation of

reservations.

Recommendations will be made for the drilling plan so that the results obtained can be best utilized.

Finally, the information obtained with oil and gas search technology (OFT) will be validated against the data held by the operating company from previously completed records using an assertiveness value at work.

4. IMPLEMENTATION OF OIL AND GAS SEARCH TECHNOLOGY (OFT)

In this chapter you will find the results that were obtained in the implementation of the oil and gas search technology (OFT), on the La Creciente Block in the Lower Magdalena Valley Basin. The execution of the three phases corresponding to this technology was carried out. Identifying the areas with the presence of hydrocarbons in the Block.

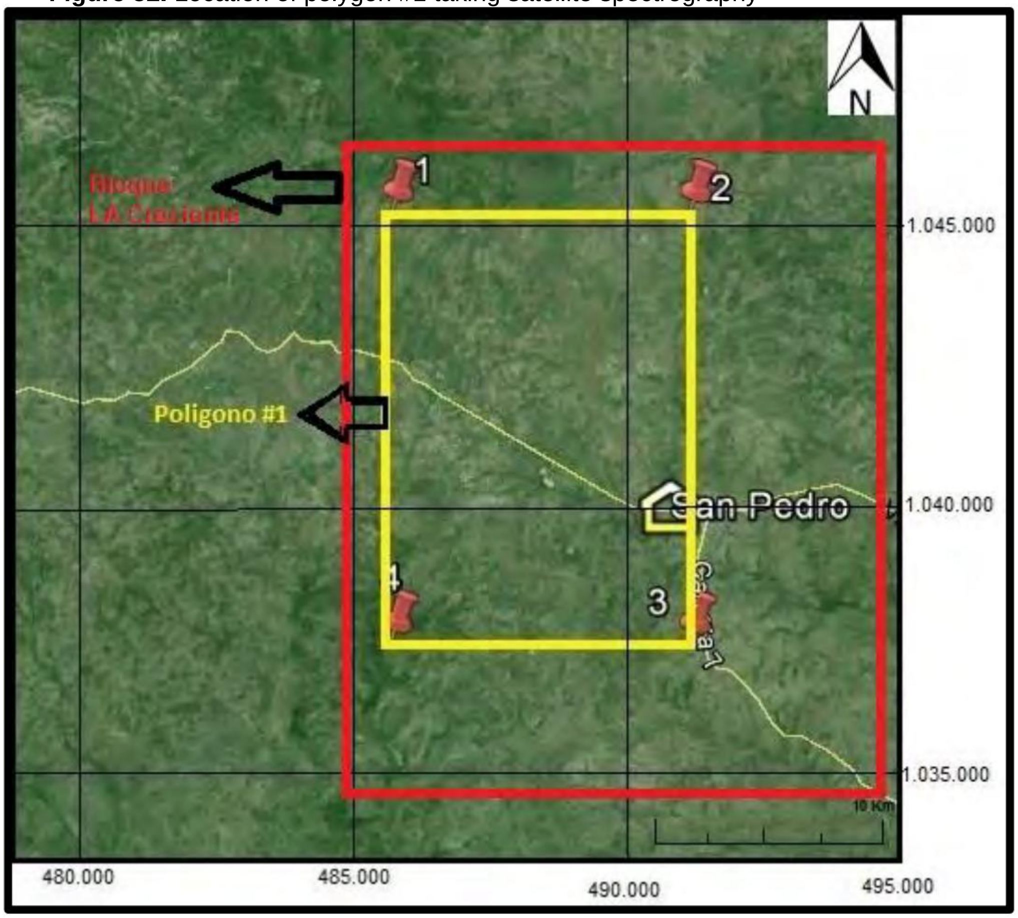
4.1 PHASE 1: SATELLITE SPECTROGRAPHY (ES)

The development of the technology seeks to have a general characterization of the field with respect to the presence, depth and thickness of hydrocarbon type fluids, this carried out on the area estimated by PACIFIC EXPLORATION AND PRODUCTION, which corresponds to an area of 89 km2, below will be shown the results obtained in the development of each phase (Phase 1 satellite spectrography, Phase 2 ECECI, Phase 3 SVER), indicating anomalous zones with the presence of hydrocarbon type fluids, selection of areas of greatest interest, determination of average thicknesses of the identified areas, gas-oil-water contact, and also determination of average pressures of the areas under study.

Satellite spectrography was carried out in the La Creciente Field, represented in satellite images, at a scale of 1:30000, to cover an area of a total of 89 km2, divided into 4 sections of 22.25 km2, thus covering the total area estimated by the company to carry out exploratory prospecting. Within this area of land, satellite data was collected, corresponding to the use of the “Resurs-P” satellite. The collection of this satellite data generates the conversion of this data into a map of electromagnetic anomalies; the area that will be found within the coordinates will be called polygon # 1.

As can be seen in **Figure 52,** corresponding to satellite spectrography in the La Creciente Field, the coordinates chosen and supplied by the operating company form polygon # 1. Within this polygon, the identification of areas with the presence of hydrocarbon-type fluids will be carried out. It is worth remembering that the operating company determines the size of the polygon and the scale at which the hydrocarbon anomalies want to be determined.

Figure 52. Location of polygon #1 taking satellite spectrography



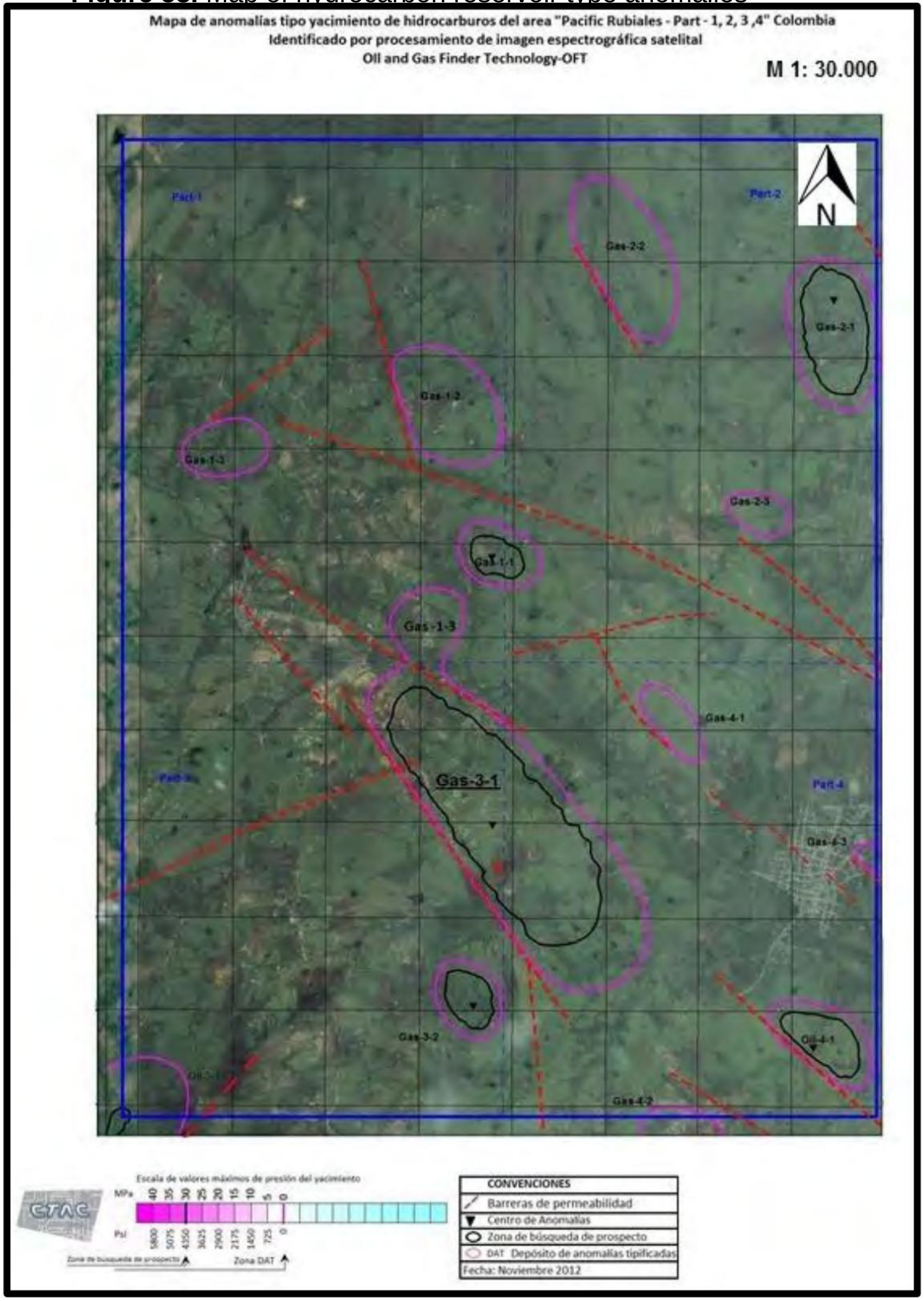
Source: Google Earth, Modified by the authors

To take satellite spectrography, it is enough to have the coordinates provided by the operating company. With these coordinates, the satellite will land on the determined area, generating the study of anomalous zones. Therefore, from the initial phase there is no disturbance to the environment in the area of interest.

Subsequently, satellite spectrography is performed, generating the interpretation corresponding to the La Creciente Field area in the Lower Magdalena Valley Basin, identifying fourteen zones distributed throughout the work area corresponding to polygon # 1 **(Figure** 53), therefore satellite spectrography managed to identify the presence of hydrocarbons in the study area, as indicated in **Figure 53,** in this image 14 anomalous zones are identified in which according to the value established for each fluid (gas, oil and water), the identification is generated, 12 correspond to zones with the presence of free gas accumulation, and the remaining 2 zones with low proportion oil accumulation or condensate fluid type.

Figure **53** shows the map of hydrocarbon reservoir type anomalies, indicating in pink the areas where there are zones with free gas type fluid and for this reason the satellite identifies them as zones with the presence of hydrocarbon type fluid, in addition the generated image locates the center of the anomaly, this zone being the point of frequency of greatest tension, added to these maps allow to relate them with the faults present in the area (permeability barriers) that will be an aspect of relation when comparing with conventional studies.

Figure 53. Map of hydrocarbon reservoir type anomalies



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

As can be seen in **Figure 53,** the location of the anomalous zones is close to the municipality of San Pedro (Sucre). Having the geological location of these, we proceed to work on the Hydrocarbon Reservoir Type Anomaly Map.

From these results, the characterization of the area begins to be structured using the tools and analysis of oil and gas search technology (OFT). In this first phase, these places are identified in the La Campo

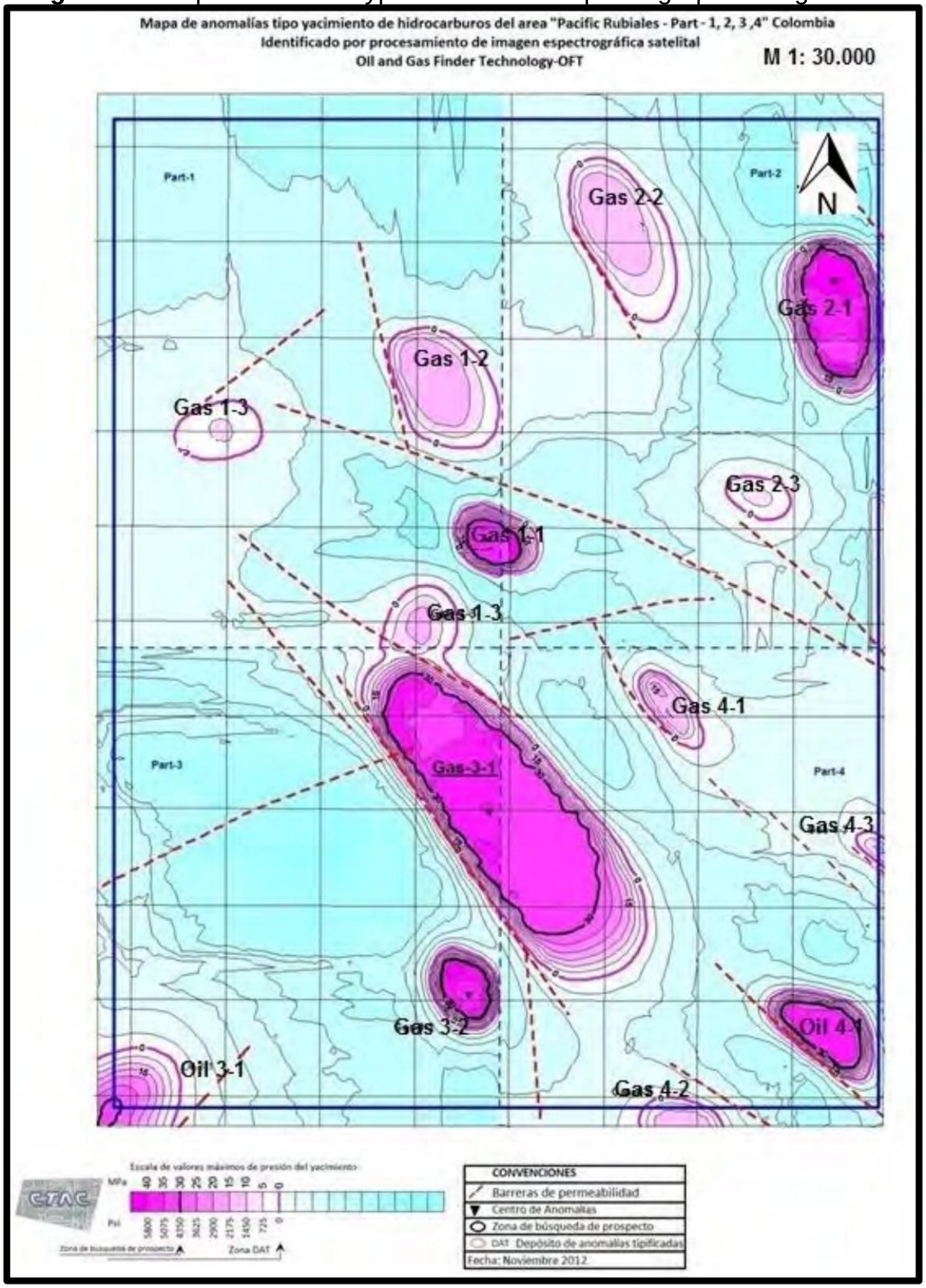
Crescent and were named as follows:

Table 4. Classification of anomalous zones according to the type of fluid identified

Anomalies with presence of gas	**Anomalies with the presence of crude oil – gas**
Gas 1-1	Oil 3-1
Gas 1-2	Oil 4-1
Gas 1-3	
Gas 1-4	
Gas 2-1	
Gas 2-2	
Gas 2-3	
Gas 3-1	
Gas 3-2	
Gas 4-1	
Gas 4-2	
Gas 4-3	

The Reservoir-Type Anomaly Map in Spectrographic Image, corresponding to **Figure 54,** shows the identified areas. Unlike the previous image, this map shows all the identified anomalies, characterized by a greater color tone as the most important places within polygon # 1, in pink are anomalies belonging to free gas type fluid and the dotted red lines correspond to the faults identified by oil and gas search technology (OFT).

Figure 54. Map of reservoir-type anomalies in spectrographic image



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

From this point, it is possible to determine which areas will be the focus of the study in the following phases. However, it is still too early to establish which areas will be the focus of the study, since the depth and thickness of the fluids will be. However, the averages of the anomalies are established, with areas ranging from 0.2 km2 to 6.7 km2 .

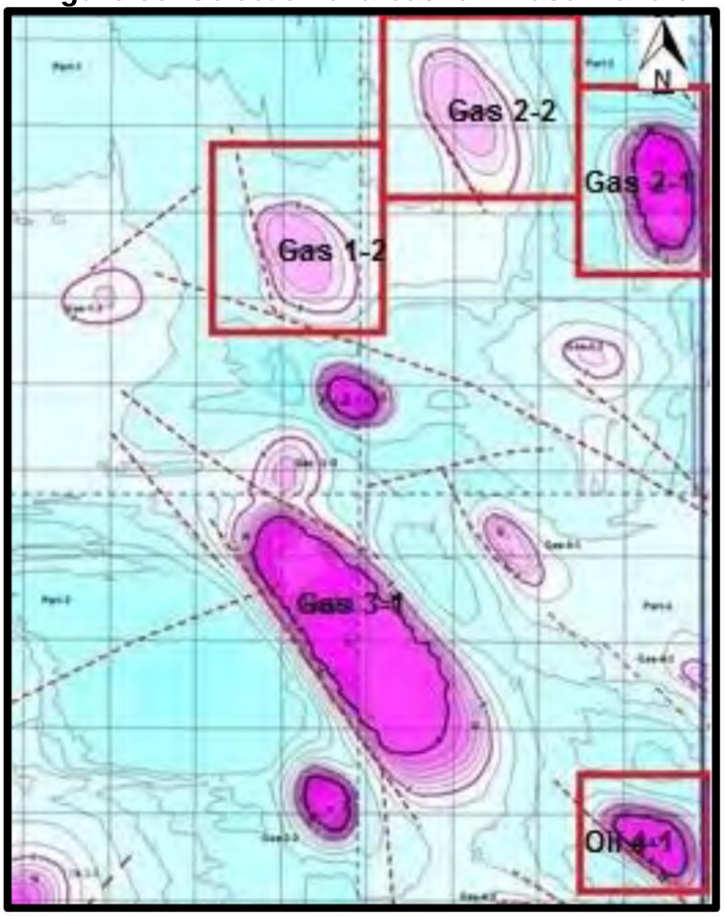
Within the central-southern part of the unified image area, the largest anomaly zone (Gas 3-1) was identified, an elongated gas reservoir type in a Northwest-Southeast direction of 6.7 km2 in extension, in which there is a record of drilled wells.
previously.

Additionally, several permeability barriers (Faults) were identified throughout all the satellite images, which can be divided into 3 main systems according to their orientation. A first system in a Northwest-Southeast direction that limits several anomalies frequently on its southwest side. A second system with a Northeast-Southwest orientation.

Once the accumulations have been established, the operating company defines which areas it wishes to continue developing the following phases, since if desired, the study can be established in each area, but this will be subject to an increase in capital allocated to the project.

Continuing with the study for the La Creciente Field, according to the hydrocarbon reservoir type anomaly map **Figure 55,** it can be differentiated (red lines) in which areas it would be worthwhile to run the following phases, since in these areas there is very little exploratory information.

Figure 55. Selection of areas for Phase 2 and 3



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.

For the execution of phases two and three, it must be established which areas within the 14 identified will be characterized and field tests will be carried out as indicated above (Phase 2 ECECI, Phase 3 SVER), for the La Campo
Growing, defining within polygon #1 the chosen areas are:

- Gas 2-1
- Gas 2-2
- Gas 1-2
- Oil 4-1

These represent the most important sectors not fully explored by the operating company within the area established for the determination of the presence of hydrocarbons, giving way to phase 2 of the establishment of a short-impulse electromagnetic field (ECECI).

However, the area called Gas 3-1 has the most information on exploratory and production projects in the area, with historical information.

supported by the operating company and the National Hydrocarbons Agency.
Within the Gas 3-1 anomaly, the La Creciente field has been developed. In this area, more than 8 exploratory and development wells have been drilled, such as:

- The Crescent 1
- The Crescent 2
- The Crescent 3
- The Crescent 4
- The Crescent 5 •

Apamate -1 •
Apamate -1X

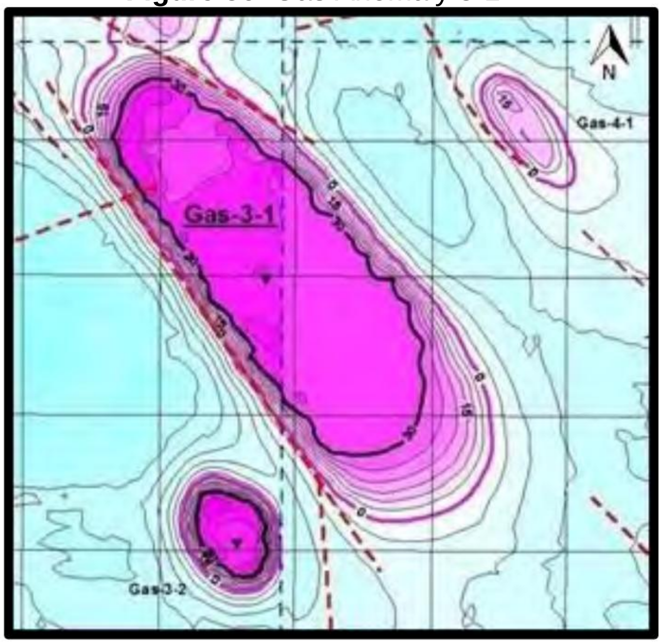
Therefore, satellite oil and gas search technology (OFT) was able to identify the largest anomaly (Gas 3-1) within the main polygon, confirming that the analysis of electromagnetic fields in the identification of hydrocarbon-type fluids, which in the case of the La Creciente Field generated the greatest presence of hydrocarbons where the exploitation of the resource is currently being developed.

As the images were obtained, the anomalies identified in the post-technology studies focused on the northern and southern parts, the central area where Gas 3-1 is located. The ECECI and SVER phases were not executed, since this area has been the place where the company has carried out the most work and information and the main interest is to detect the areas in which it has not been possible or in which there is a minimum of exploration by it.

In Chapter 2, the Gas 3-1 zone is the area that confirms the veracity of the technology, since the existing information on the drilled wells and the seismic studies carried out show that the compilation of this information characterizes the La Creciente Field, and that the anomalous zones indicate that the presence of hydrocarbon-type fluids can be confirmed by the information already confirmed and that the existing paradigms are really broken in relation to non-conventional methods of hydrocarbon exploration.

Figure **56** corresponds to the anomaly generated in the study of the lifting of a spectrographic image, within which are found the majority of wells belonging to the La Creciente Field, this anomaly has an approximate area of 6.7 km2 .

Figure 56. Gas Anomaly 3-1



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, Modified by the authors

4.2 PHASE 2: ESTABLISHMENT OF ELECTROMAGNETIC FIELDS OF SHORT IMPULSE (ECECI)

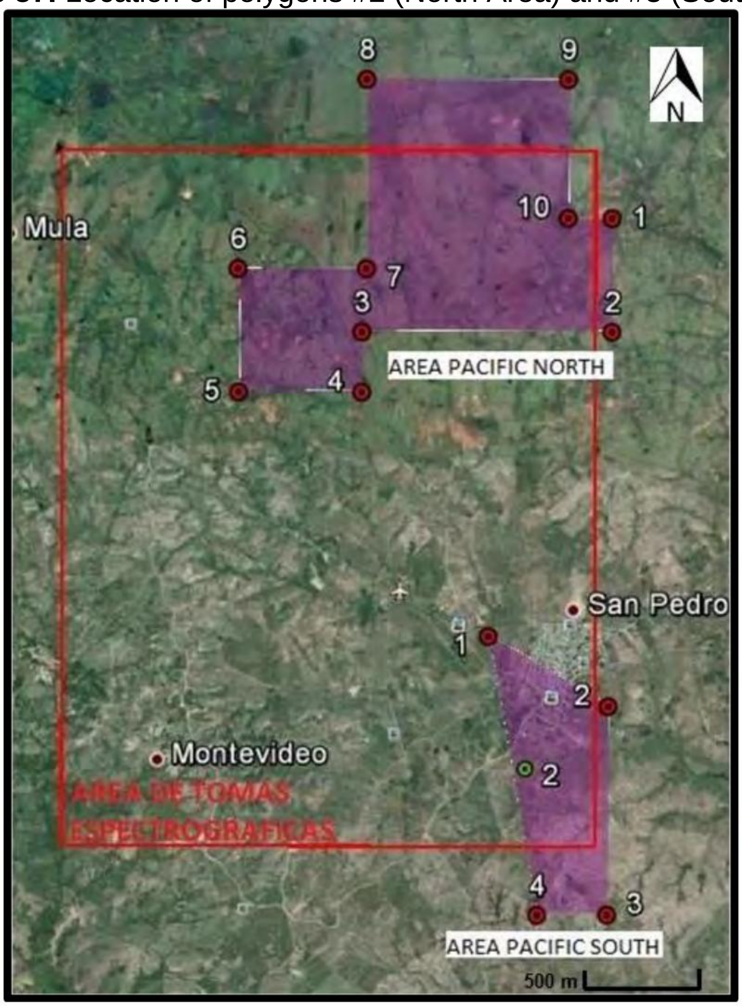
For the development of the second phase of data acquisition of the oil and gas search technology (OFT), according to the identification of the main structures chosen (Gas 2-1, Gas 2-2, Gas 1-2 and Oil 4-1), the tests are carried out in the area of influence of the project, it is important to mention that according to how the development of the technology progresses, the characterization area decreases in relation to the area but increases its effectiveness, having in the main stage the polygon # 1 of 89 km2 **(Figure** 52), already in the second phase within polygon # 1 the operating company determines on which area the data acquisition in the field is concentrated, for the case of the La Creciente Field, as previously named the areas of interest selected for this phase are Gas 2-1, Gas 2-2, Gas 1-2 and Oil 4, these areas will be distributed to form new polygons on which the data acquisition is carried out, advising the company that in accordance with the anomalies identified, the area of these has a percentage greater than around 15% of the area of the anomaly, this in order to cover a larger study area in case the anomaly has not been discovered in its entirety or covers a larger area.

As can be seen in **Figure 57,** the new polygons determined concentrate the chosen structures, generating new acquisition and study coordinates. These new polygons in many cases exceed the initial limits of the main polygon since what is desired is to study the anomalous area and its surroundings.

According to this determination, the work area will be divided into two zones, called polygon #2 the North Zone and polygon #3 the South Zone. Both the North Zone and the South Zone exceed the coordinates of polygon #1, in order to be able to detail and characterize the size of the presence of fluids to the maximum extent possible.

As seen in **Figure 57,** the new coordinates are defined for polygon #2 and polygon #3, these two located within polygon #1, for the La Creciente Field, Lower Magdalena Valley Basin.

Figure 57. Location of polygons #2 (North Area) and #3 (South Area)



Source: Google Earth, Modified by the authors

The execution of the following phases, such as their development, is carried out in the field. Therefore, before taking data, the access routes and places where it is possible to take data must be determined on site, always respecting the environment of the area and generating the least possible impact.

For La Creciente Field, it was necessary to resort to data acquisition from a pickup truck, and in places where vehicular access was not possible, data was collected from the assembly of equipment loaded by pack animals (horses). In the case of vehicle use, data acquisition was carried out on the roads established by local people. For vehicles, the average speed was 20 to 60 km/h.

For Phase 2 ECECI, the center for generating and receiving the excitations of the surface electromagnetic field does not have to be fixed and anchored to the surface, which is why it is carried in the transport equipment mentioned above, unlike what happens with Phase number 3 SVER, which will be discussed later.

The data collection relationship was outlined as follows, performing wave shots (generator) of electromagnetic field excitation according to the proximity of the anomalies in an established order from 25 to 50 meters (28 and 164 feet), for the new polygons (#2 and #3, **Figure 57)** it is determined to take the shot at 22 points distributed between the North Zone and the South Zone.

The ECECI method forms a short electrical impulse field generated in small dipole ferrite antennas. These sections allow to differentiate the anomaly zones with deposit-type zones. In these zones, the amplitude and temporal characteristics of the process of establishing a field in the receiving ferrite antennas are measured.

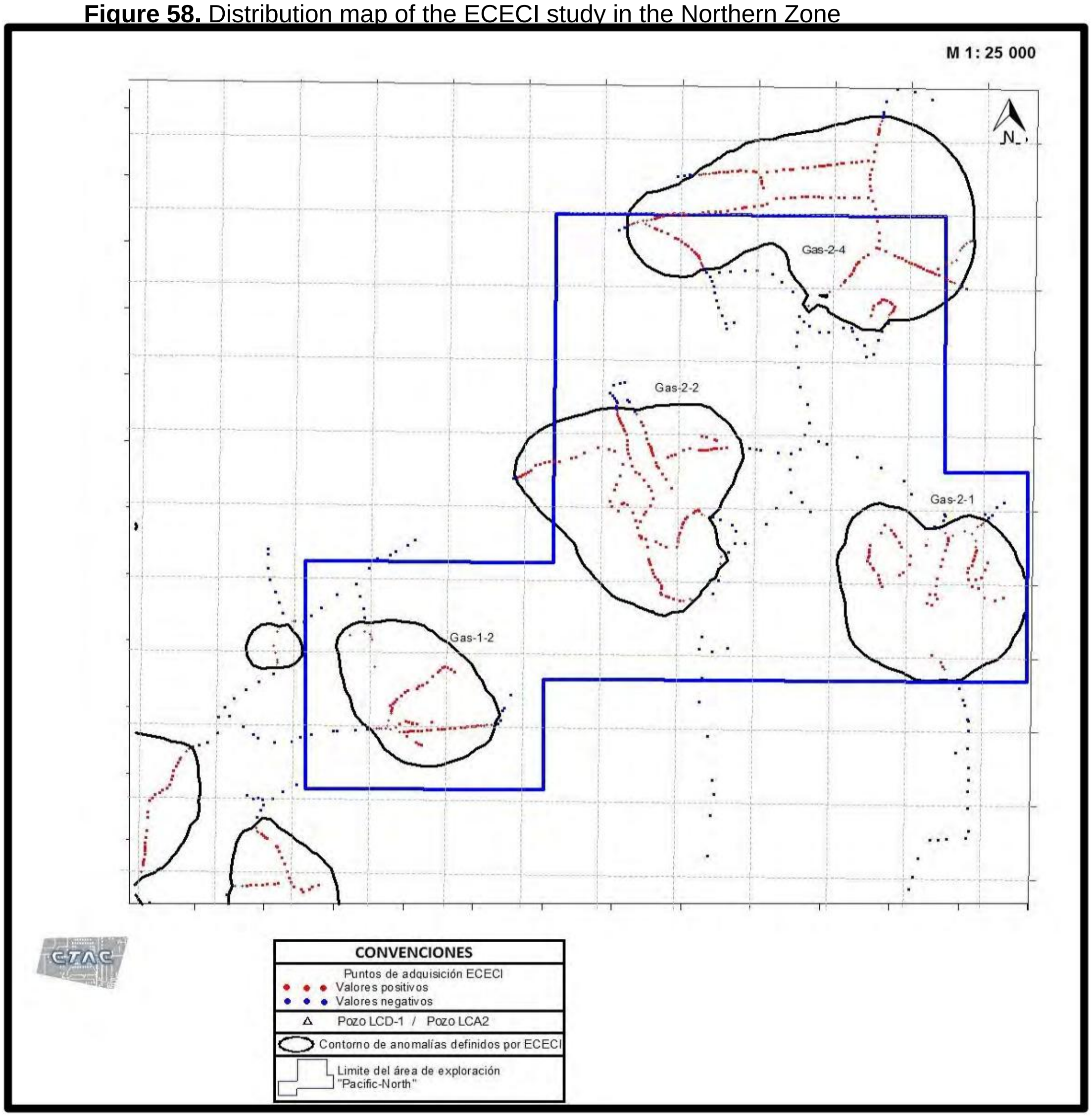
These results are obtained in real time, from the location where the recording point is centered on the search for oil and gas, so as the data collection is simultaneous, the results analysis software models the anomalous zones that were identified in Phase 1 of spectrometry, with established coordinates it will indicate whether it is within the anomaly or on the contrary the sample points are outside the anomalous zone.

Data acquisition was carried out along different transit routes, which cross the areas defined for the field study where they had previously been identified by spectrometry.

As can be seen in **Figure 58,** corresponding to polygon #2 of the
Northern Zone defined in phase two of ECECI, indicates that if the route is within the anomaly, the data collection and points for analysis will show a red indication as seen in **Figure 58,** contrary to what it indicates when the reference point of the data collection turns blue indicating that it is

outside of the anomaly of the presence of hydrocarbons, already in this stage of development of the technology in the La Creciente Field, the initial form of the structure in a greater percentage took a different form, now resembling more the most precise location of the fluids of interest (hydrocarbons), for the northern zone it was possible to identify that within the anomalies of the zone there were some important characteristics that had not been identified in phase 1 of spectrography, which proportional to polygon # 1 did not cover the entire study area but nevertheless in the resolution of the map of polygon # 2 allowed to show that a large part of this perhaps the most considerable area was outside the study and area of the field operators, this new zone was defined as Gas 2-4.

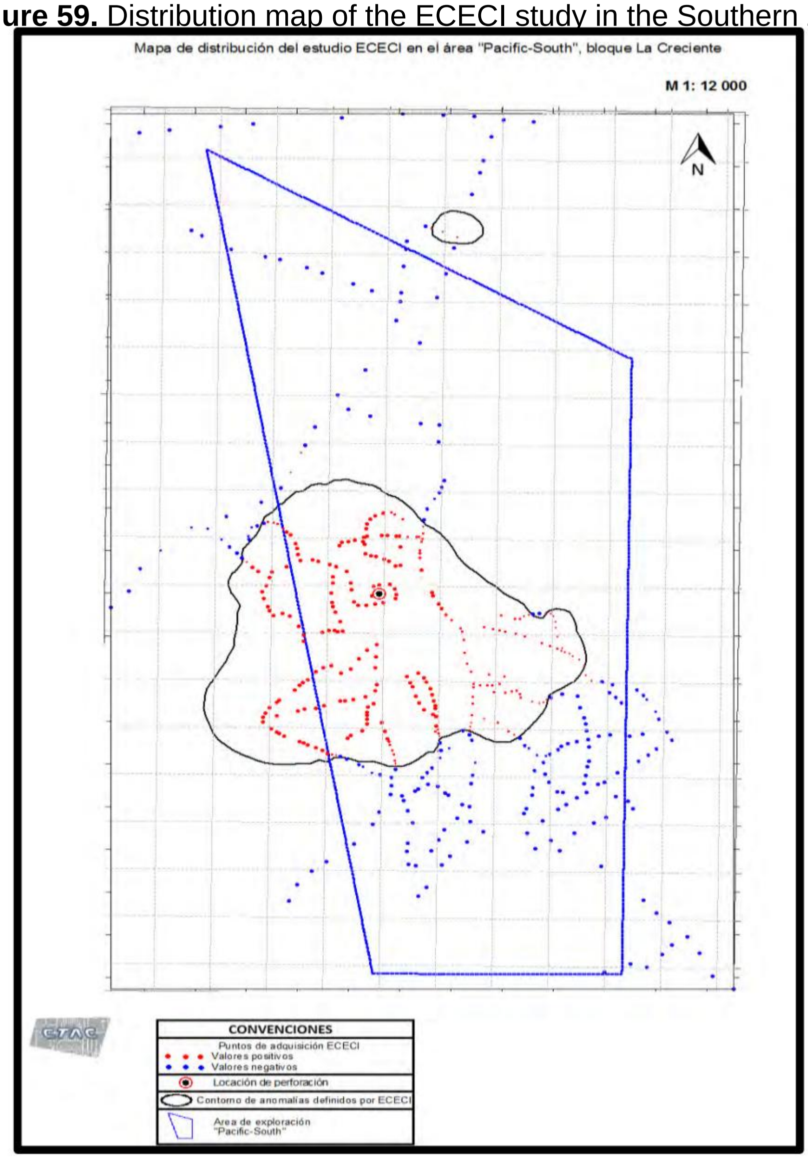
Figure 58. Distribution map of the ECECI study in the Northern Zone



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

The same occurs with the southern area defined in phase two corresponding to polygon #3, in this defined area the points were taken in the field, as seen in **Figure 59,** corresponding to Zone Oil 4-1, according to the point trend, if it is red, it belongs to the route that was taken within the anomaly, unlike in the areas with blue trends that indicate that the data collection is outside of it, the area definition of the zones is linked to the completion of the three study phases, on this occasion in the southern zone corresponding to Oil 4-1, the initially defined area does not cover the entire size of the structure but nevertheless shows its delimitation and is verified when the data is taken in the field.

Figure 59. Distribution map of the ECECI study in the Southern Zone



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

During the Phase 2 ECECI data acquisition and real-time processing, they used the resonance frequencies for oil, free gas and dissolved gas in water. With the processing of the ECECI results, within the limits of the northern and southern areas studied, the zones previously identified with spectrometry (Gas 2-1, Gas 2-2, Gas 1-2 and Oil 4-1) were confirmed.

Additionally, at the edge of the Northern Zone, where no spectrometry had been performed, a gas deposit-type anomaly was found. This was conditionally called Gas 2-4.

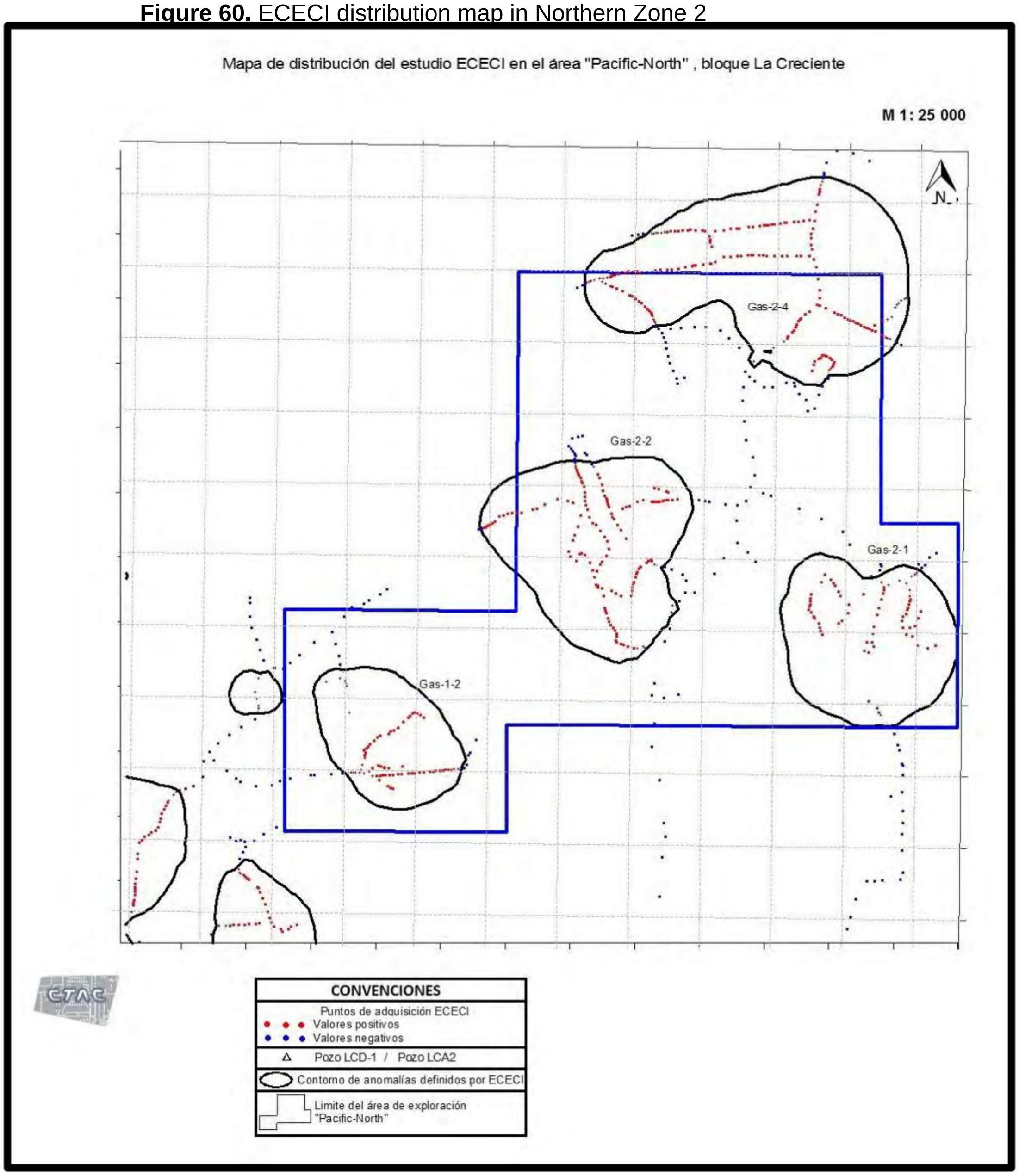
Almost half of the Gas 2-4 structure was located within the assigned study area belonging to Pacific, while the other part, further north, is located within the Hocol company block.

Some of the anomalies were detected in areas close to the LCA-2 exploitation well and the “Apamate-3” well. In the vicinity of “Apamate-3”, free gas or natural gas frequencies were not detected. The structure corresponding to this well can be identified as a zone of water saturated with dissolved gas.

Based on the results of the geoelectric study for each of the areas, contour maps of the hydrocarbon deposits were made, in addition to the columns and vertical sections corresponding to phase 3 SVER. In field work, the anomalies and the prospectivity of each of them will be defined.

- **Result polygon # 2 North area.** According to the results obtained in phase 2 of ECECI, the depth, average thickness and approximate pressure that the areas of interest may present (Gas 2-1, Gas 2-2, Gas 1-2 and Gas 2-4) are characterized, the analysis of these 4 zones correspond to gas deposits **(Figure** 60), determining the approximate depth of the gas deposit levels, which will later be compared with the corresponding Phase 3 using the SVER method.

Figure 60. ECECI distribution map in Northern Zone 2



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Below is a description and analysis of the structures identified in the North area:

ÿ **Gas Anomaly 2-1.** In the identification and characterization by means of the technology for the search for oil and gas (OFT), the Gas 2-1 structure is located in the North Zone, lower corner of polygon # 2, and is made up of an area of 1.43 km2 , It is also worth noting that the producing well called LCD-1 is located in the center of the anomaly.

The identification was carried out by using the frequency used for free gas, in each of these, for the Gas 2-2 structure, field work was essential regarding Phase 2 ECECI, as seen in Figure **60,** the trend of red dots is distributed along the anomalous zone (red dots) by the color tone, indicating a strong presence of gas, Phase 2 of ECECI was also executed, in the larger area identified by the points and trends in red.

ÿ **Gas 2-2 Anomaly.** The Gas 2-2 structure, located in the northern area of the data collection with the technology for the search for oil and gas (OFT), is situated in the central area of polygon # 2, with an area of 1.82 km2 , Like the Gas 2-1 structure, this was detected with the resonance frequency for free gas type fluid, added to the tonality shown in **Figure 60,** this anomaly confirms the presence of free gas type fluid.

The importance of carrying out the three phases in a given area is directed towards the complementation of each of these; for the Gas 2-2 structure, field work regarding Phase 2 ECECI was essential, as observed in Figure **60,** the trend of red dots is distributed along the anomalous zone (red dots).

ÿ **Gas Anomaly 1-2.** Located over the northern zone, this structure has an area of 0.012 km2 , with respect to the northern area, it is located in the western part of the polygon area # 2, the results of Phase 2 ECECI indicate a low to faint signal regarding this anomaly in relation to the color tone in **Figure 60,** the frequency of free gas was detected in a very small fraction, however, it is identified with the presence of fluids, even if to a small extent.

ÿ **Gas 2-4 Anomaly.** Called Gas 2-4 structure, this has something in particular, it is also located over the area of polygon # 1, but identified in polygon # 2 of Phase 2 ECECI, and the northern zone with an upper location, however, as seen in **Figure 60,** the structure is located partly within the study area but the limits established initially mean that a good part of the structure is not within the identification and according to information from the operator it is outside the limits operated by PACIFIC, however, in this area the part belonging to the operator indicates the presence of free gas fluid and the area that can be used by the company corresponds to 0.24 km2

, with a larger area of anomaly but not belonging to the main operator, with an average thickness of 8 meters.

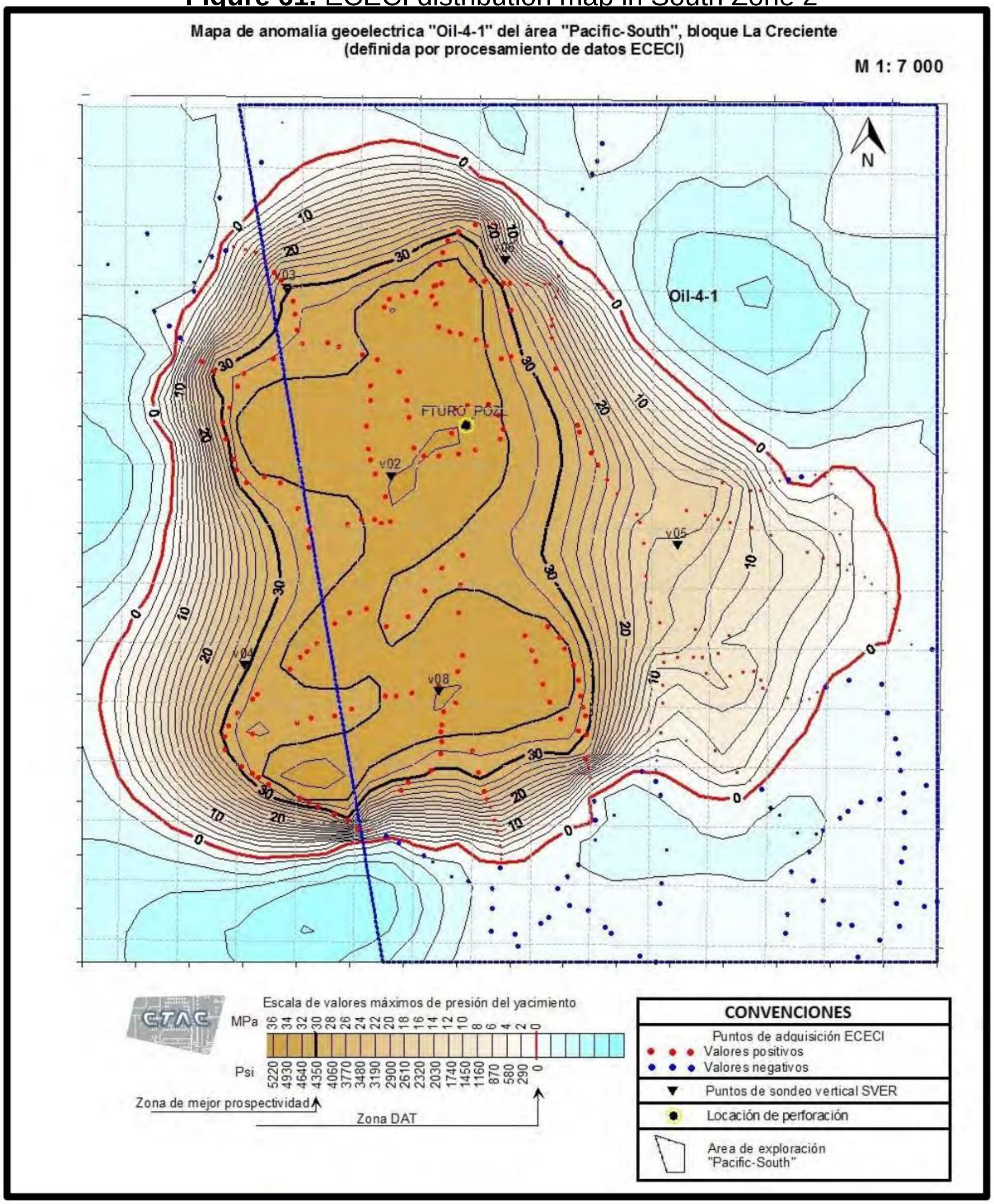
- **Result polygon # 3 South area.** It is worth remembering that the initial polygon of 89 km2, an area of 22.25 km2 was covered , divided into two polygons corresponding to the northern zone, previously addressed and the southern zone corresponding to the lower zone of the main polygon, for this zone it was projected to study the anomalous zone Oil 4-1, this southern zone is located near the municipality of San Pedro (Sucre), by spectrometry results (Phase 1), a gas-crude type geoelectric structure was identified; once this was established, it corresponded to carry out the field test corresponding to Phase 2 ECECI, in the route of the data collection of this structure it was possible to identify according to the response of the excitation of the electromagnetic medium with response to red dot trend indicating that the collection was being done within the anomaly, covering most of it thanks to the various access points.

This structure is different from the others because according to **Figure 61,** it has a light brown contour tone, which according to the ECECI study, the entire area is detected by the oil resonance frequencies. This structure is made up of an area of 1,312 km2.

, also in

In the central part, natural gas is also recorded by the resonance frequencies obtained. It can be established according to the results that this anomaly records the behavior of a crude oil reservoir with a gas layer. This will be established in Phase 3 corresponding to vertical sounding, which will be addressed later.

Figure 61. ECECI distribution map in South Zone 2



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

As planned, the operator was also conducting field work in the center of the anomaly, while location work was being carried out for the drilling of a future well.

4.3 PHASE 3: VERTICAL ELECTRO RESONANCE SOUNDING (SVER)

For the final phase of development of the oil and gas search technology (OFT), the areas with the presence of hydrocarbon-type fluids must be established, as well as the areas where the signal has the highest frequency, among other factors that determine the vertical survey points. This is why, in the work carried out on the La Creciente Field, in the Lower Magdalena Valley Basin, the data collection points on which the vertical survey will be carried out are located.

This method allows rapid separation of segments at each survey point from the stratigraphic elements and determination of the depth of their occurrence with pressure.

The most important thing about the SVER method is that the abnormally polarized layers of "Oil", "Gas", "Water", "Salt", "Crystalline basement", etc., the capacity and depth at which they are located, are determined not by solving inverse problems, as is usually done in almost all geophysical methods, but are defined in the process of measurements directly from the technologically developed experimental system of measurements along the lines.

The SVER method of sounding detection is based on the study of natural processes of mean polarization and the spectral characteristics of the natural electric field over a reservoir.

Geoelectrical sections and area sections are constructed to a depth of 5 km (16,400 ft). In this range of measurements in the assigned areas, the zones of deposit-type anomalies are identified.

Phase 3 SVER is carried out on the areas where it was determined to carry out Phase 2 ECECI, and in the area of each of these areas, suitable locations are chosen to record, by means of vertical sounding, the depth at which the fluids of interest are located, as well as to determine their thickness and average pressure, and also to identify the depth of the basement, which makes this phase a confirmation phase on the data obtained and analyzed so far.

Likewise, as determined in Phase 2 for the La Creciente Field, the areas chosen to carry out the study of the area such as Gas 2-1, Gas 2-2, Gas 1-2 and Gas 2-4 for the northern area and the anomalous zone Oil 4-1 for the southern zone, this in reference to the corresponding area within polygon # 1, will remain the same for Phase 3 SVER.

The union of these SVER points allows a correlation to be made between these measurements and thus form vertical profiles corresponding to the anomaly.

Phase 3 SVER results for the North Zone polygon #2. For the North Zone, the study will be based on the structures Gas 2-1, Gas 2-2, Gas 1-2 and Gas 2-4. For each zone, between 2 and 6 vertical survey data collection points or SVER points will be established. It is important to remember that this data collection must be carried out with the generating equipment fixed to the surface.

Within the 22 points established for data collection, the following 16 points were assigned to the North zone:

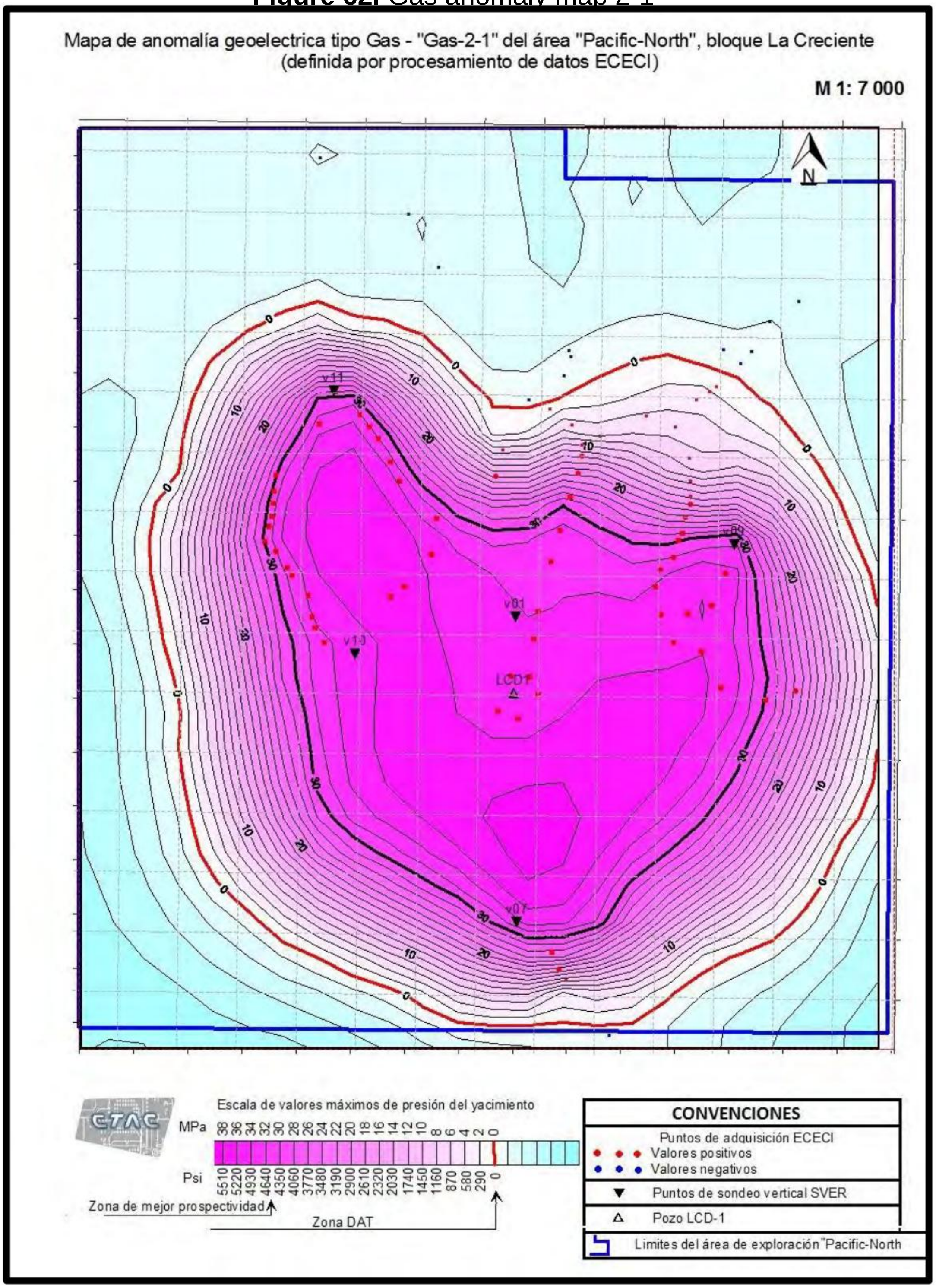
Table 5. SVER Points Northern Zone

Anomalous Zone	**SVER Points**
Gas 2-1	V01, V07, V09, V10, V11
Gas 2-2	V12, V13, V14, V15, V16
Gas 1-2	V17, V18, V19
Gas 2-4	V20, V21

Gas 2-1 Anomaly. For this structure, the points were located at the limits of the same, having the points V01, V07, V09, V10, V11 **(Figure** 62), according to the results obtained in the vertical sounding, allows to correlate each point belonging to Gas 2-1 and obtain a vertical profile of the anomaly, which in the case of Gas 2-1, were called the vertical sections PrN1 and PrN2, for their corresponding interpretation.

Figure **62** shows the anomaly map, Gas 2-1, corresponding to a scale of 1:7000, where the location of the points for taking the vertical surveys can be observed. It is also worth noting that the LCD-1 well is located within the anomaly in this structure.

Figure 62. Gas anomaly map 2-1

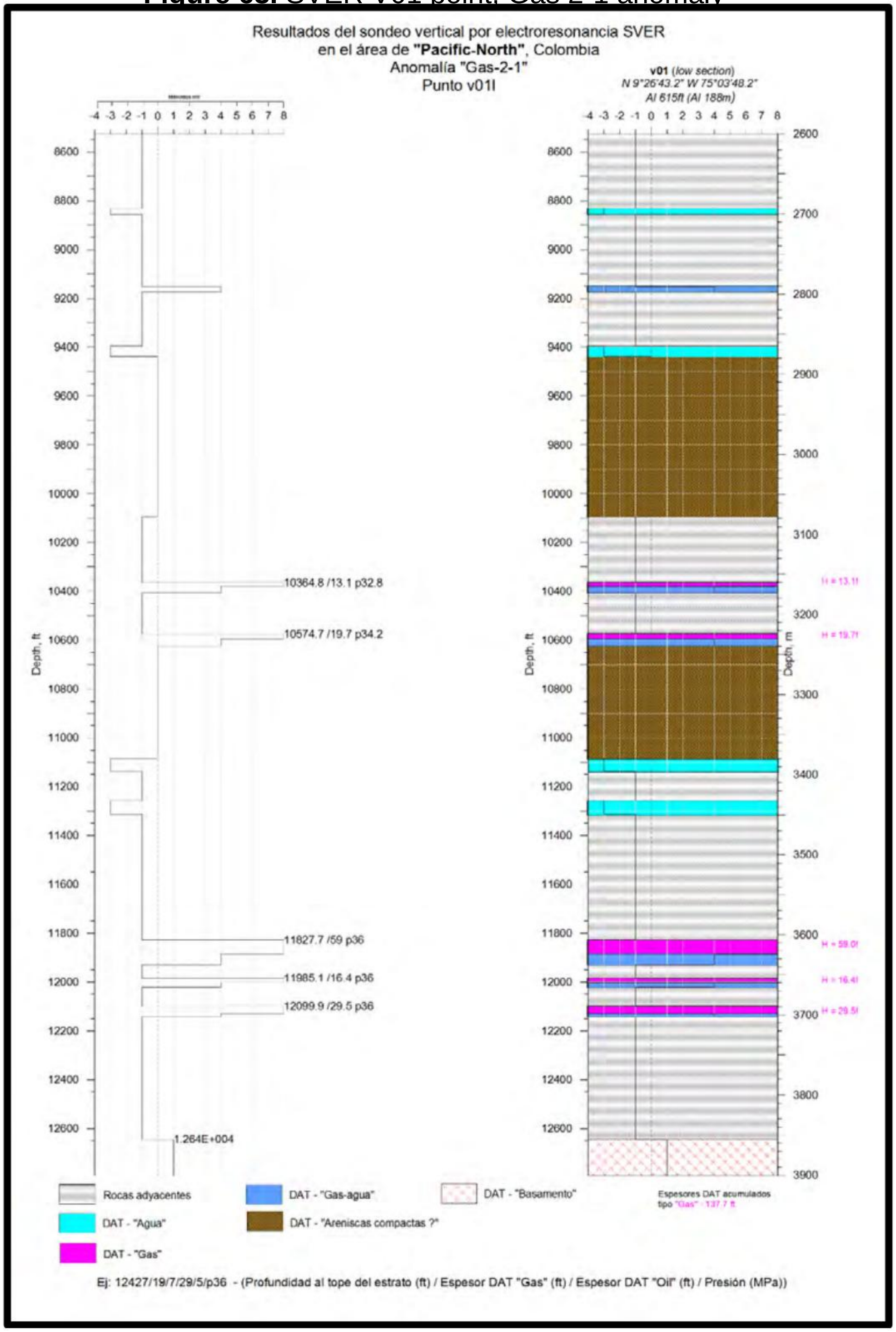


Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.

Taking each vertical survey point in the areas allows obtaining a vertical image of the depth, identifying mainly fluids such as gas, oil and water, contacts of these fluids, certain lithological material and finally the depth at which the basement is located.

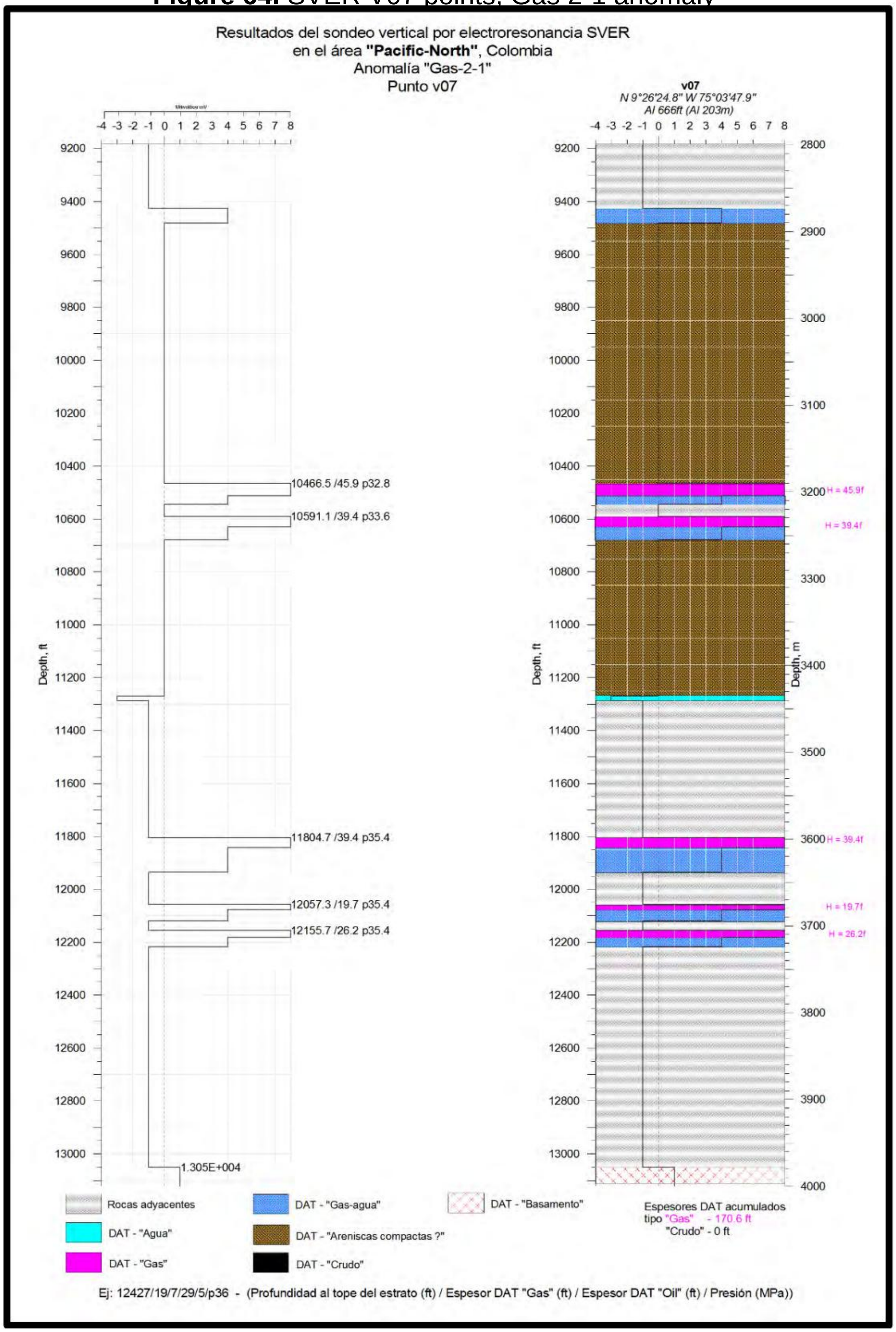
This is why for each point there will be an adequate correlation, as seen in **Figure 63, Figure 64, Figure 65,** corresponding to the vertical sounding point called V01 **(Annex A),** V07, V09 **(Annex** B), V10 and V11 **(Annex** C), the column on the left side corresponds to its reading in millivolts (mV), likewise the column on the right side allows to interpret according to the value established in column one the presence with depth of fluids such as gas, crude oil and water.

Figure 63. SVER V01 point, Gas 2-1 anomaly



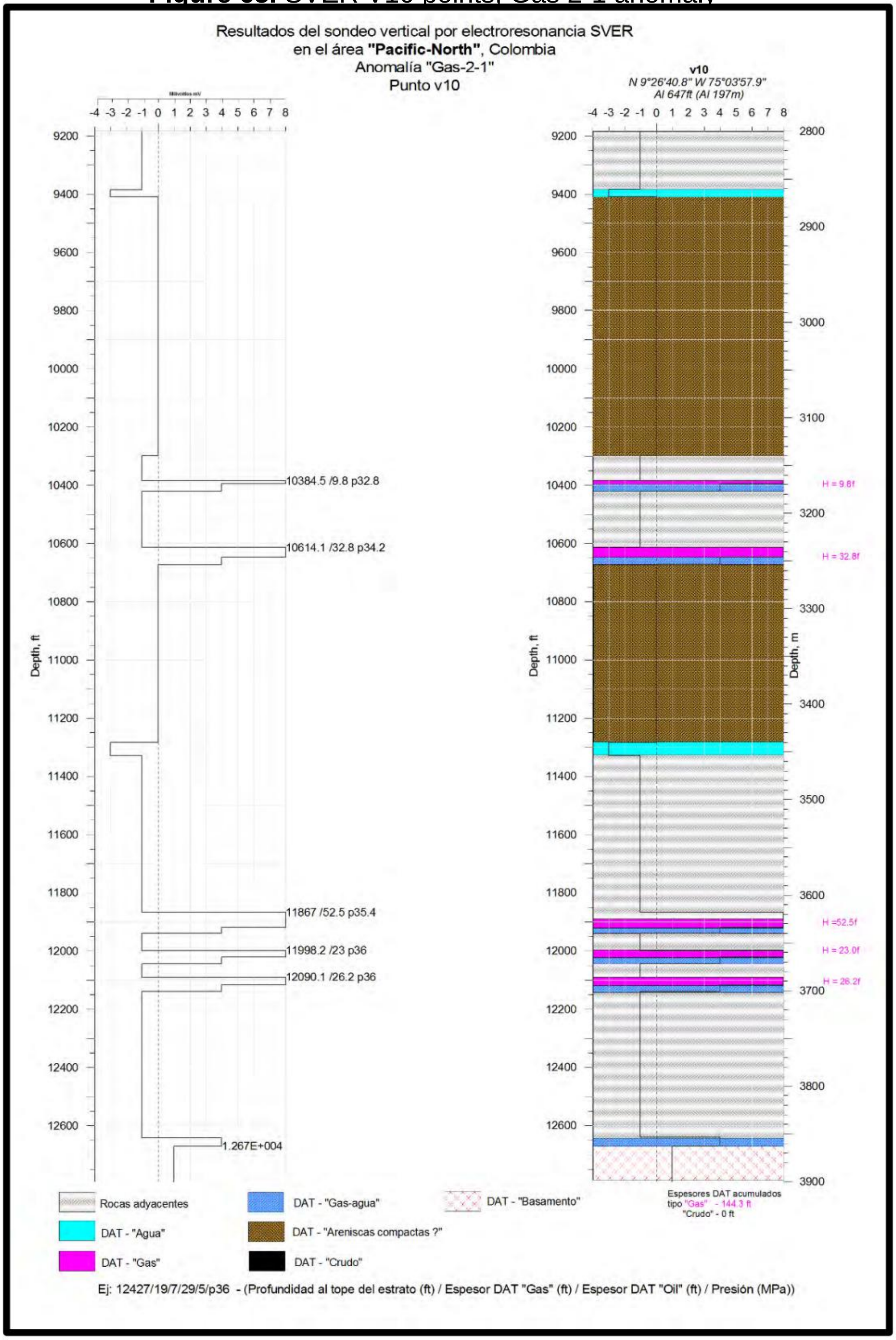
Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Figure 64. SVER V07 points, Gas 2-1 anomaly



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Figure 65. SVER V10 points, Gas 2-1 anomaly



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

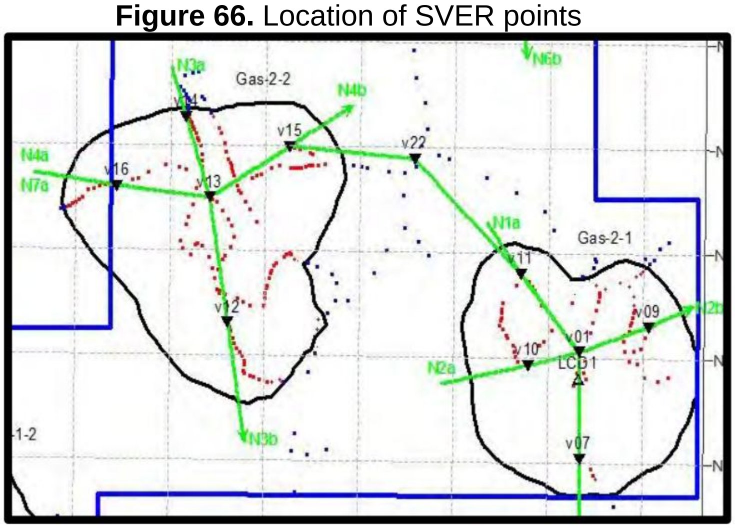
As the vertical survey points V01, V07, V09, V10, V11 were established, these points were taken in the areas established by the company's specialists to identify the hydrocarbon type fluids, within all these points you can see the depths at which the different fluids are found within the identified anomalies, as well as the depth of the basement, which the value obtained in Phase 3 of SVER, is compared with the existing information of exploratory wells that have been carried out by the operating company.

The analysis of these points will be correlated with the union of all the points taken, which generates a lateral profile of the Gas 2-1 type structure, which will be addressed in the following pages.

However, as the study wishes to cover a characterization of as much of the area as possible, the oil and gas search technology operators decided to take an additional point but it did not converge with any of this area, for this reason the point V22 was taken between the structures Gas 2-1 and Gas 2-2, in order to correlate the depths that are presented and that with the taking of this point it is possible to increase the size of the profile created and that encloses in a single image the structures Gas 2-1 and Gas 2-2.

Figure **66** indicates the place chosen to take the point called V22, this point is located outside of Gas 2-1 and Gas 2-2.

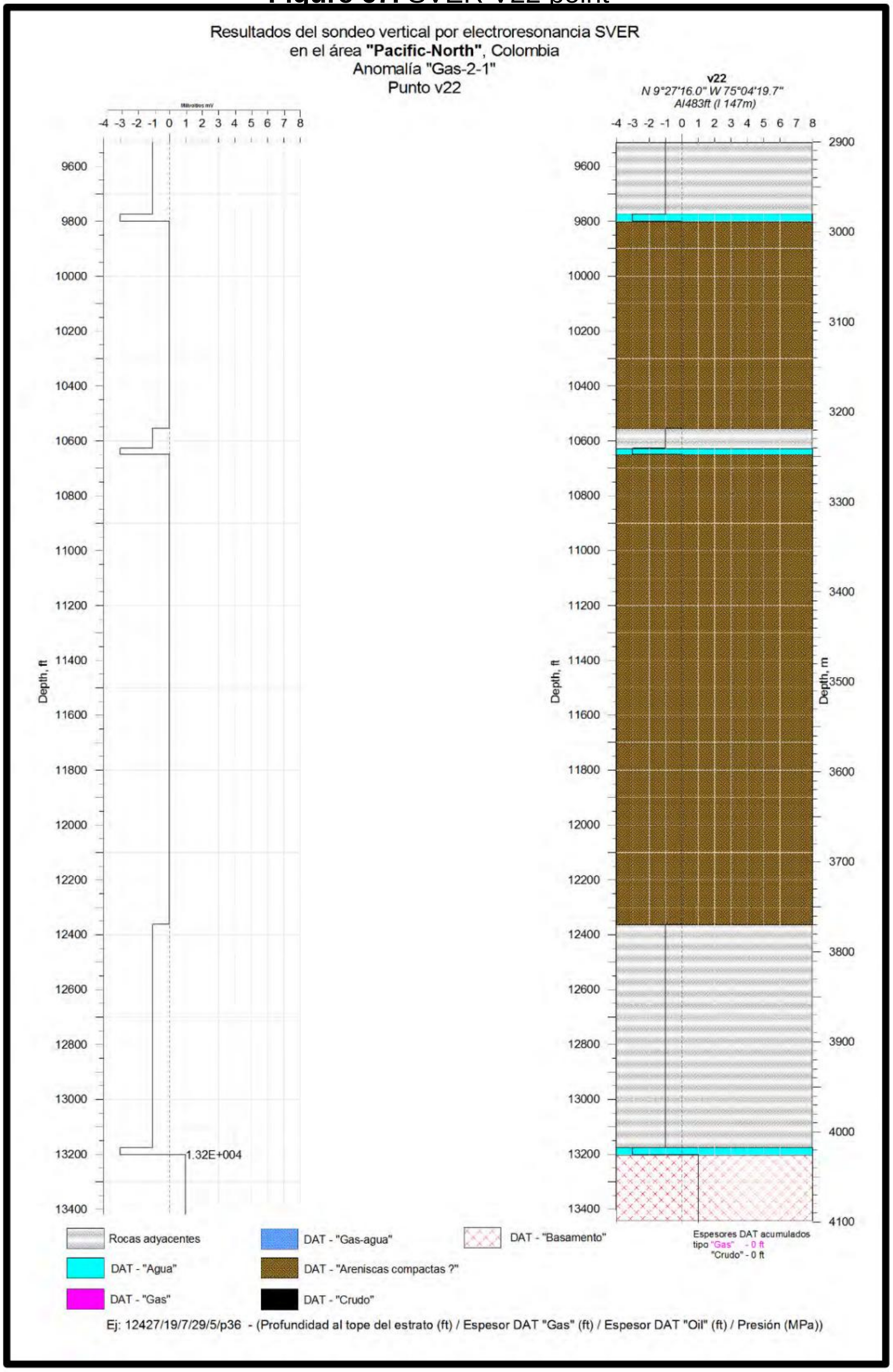
Figure 66. Location of SVER points



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.

The point outside these V22 anomalies, I present the following correlation corresponding to **Figure 67.**

Figure 67. SVER V22 point

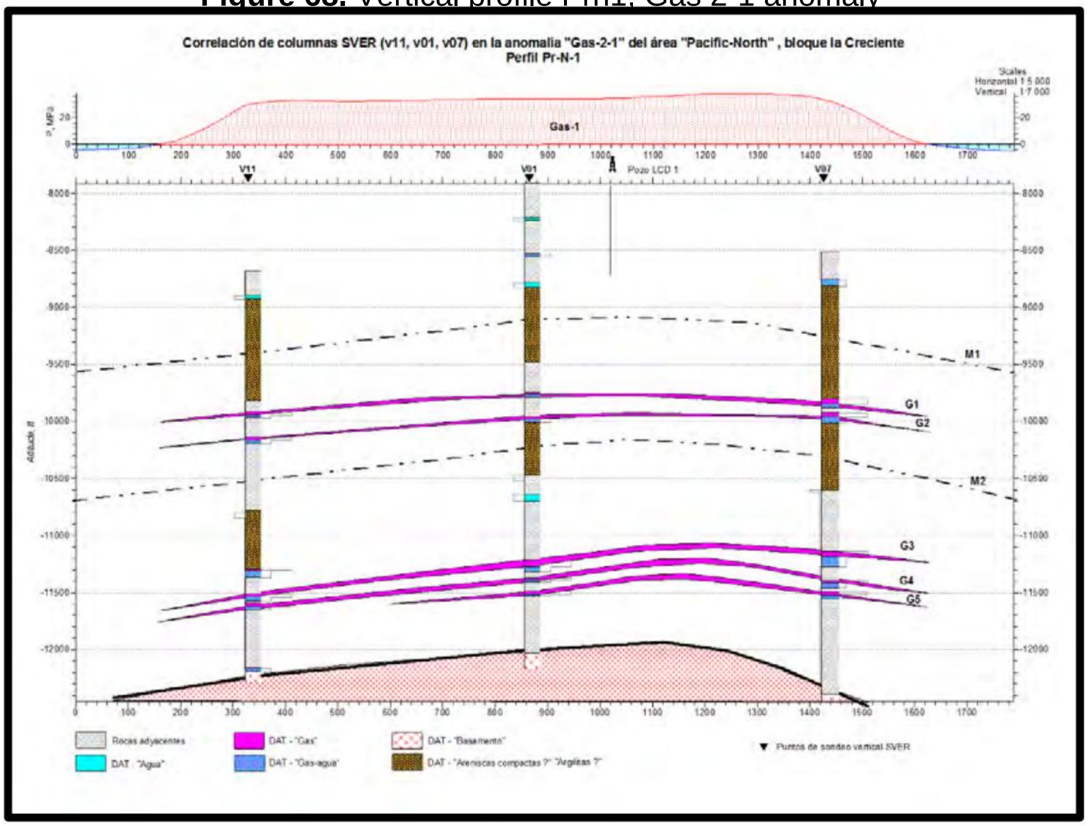


Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

The union of these vertical sounding points allows generating a profile of the entire area, as seen in **Figure 68,** the union of these points is intertwined generating the correlation and verifying that the strata where the fluids of interest corresponding to each vertical sounding are located have a correlation with the other strata of the points, likewise the continuity of the fluids of interest can be modeled, which in this case the La Creciente Field, corresponds to free gas type fluid.

Figure **68** shows the correlation and union of the points belonging to the northern zone of Gas 2-1, the points joined for the formation of this profile correspond to V01, V07 and V011. Thanks to this profile, the presence of gas can be observed between the depths of 10,300 - 10,600 feet and 11,800 - 11,900 feet.
12,200 feet, and the depth at which the basement is located (12,700) was also detected, as well as its continuity throughout the area, confirming the high resolution projected by Phase 3 SVER, of the oil and gas search technology (OFT).

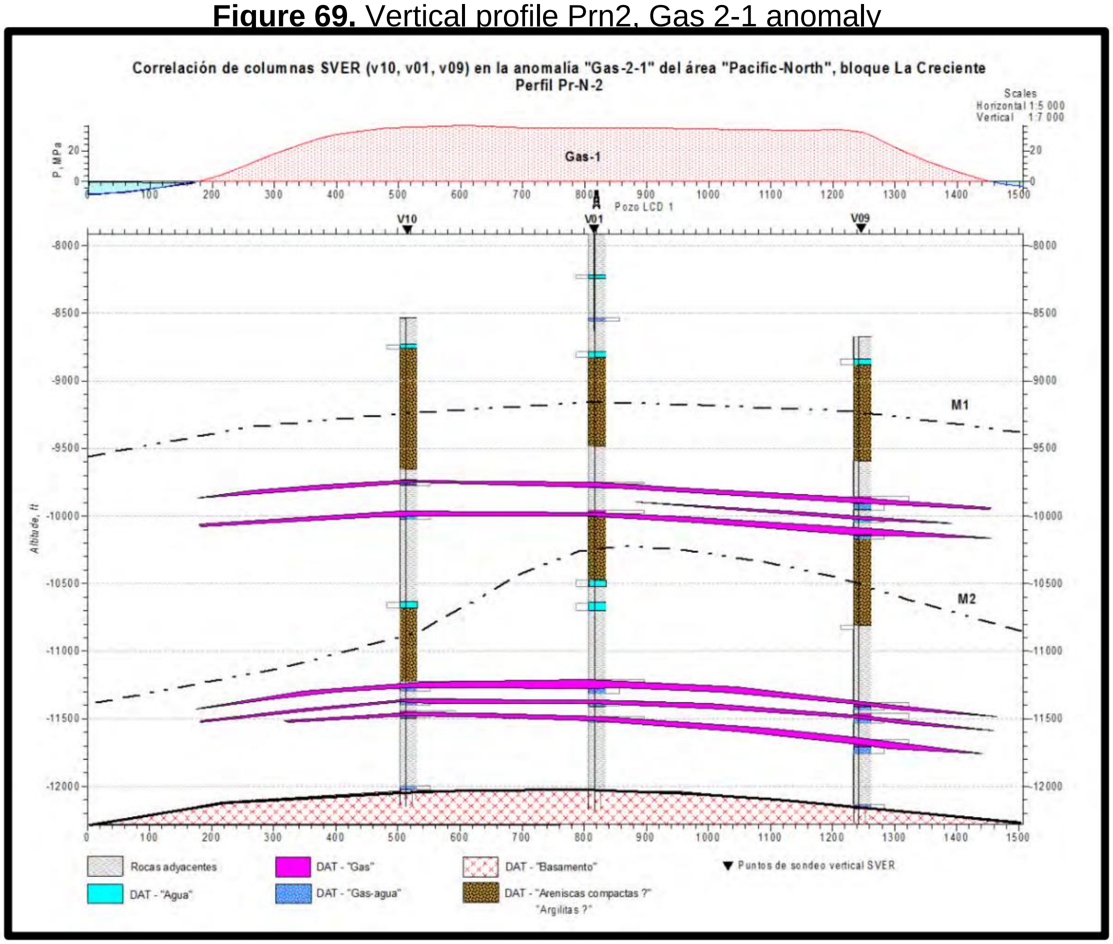
Figure 68. Vertical profile Prn1, Gas 2-1 anomaly



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.

Figure 69, corresponding to the union of the vertical sounding points V01, V09 and V10, in addition to these points is the well drilled in the area called LCD-1, as in the profile Prn1, this profile confirms that the union of the vertical sounding points forms an optimal and adequate profile correlating the depths of each point, in addition it structures the areas where the reservoir type fluids are stored.

Figure 69. Vertical profile Prn2, Gas 2-1 anomaly



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

The union of the intervals generates the profiles of the study area Prn1 and Prn 2, in these profiles the depths at which hydrocarbon type fluids and groundwater were detected are observed, these identifications were carried out according to established values for free gas type fluid, water among others.

As the depths and points were compared, the following aspects were determined:

- Horizontal aquifer intervals and dissolved gas reservoirs were identified in water.

- Basement rocks were identified, located at an approximate depth of 12,700 feet, with a measured depth of up to 14,760 feet.

- The intervals from 10,300 feet to the basement 12,200 feet, two levels were detected, in which the presence of free gas type fluids is found, these two levels are separated by compact layers of argillite type (claystones) and/or compact sandstones.

Within these two intervals the intervals 10,300 – 10,600 feet and 11,800-12,200 feet will be the intervals of interest.

The first interval identified was found:

Table 6. Fluids identified stratigraphic level 1 anomaly Gas 2-1

Stratigraphic level number 1	
Layer 1: Free Gas Layer 2: Free Gas Depth: 10364 – 10466 ft	
Depth: 10574 – 10644	
Average thickness: 29.5 ft Average thickness: 26.3 ft Approximate pressure: 32.8	
Mpa Approximate pressure: 34 Mpa	

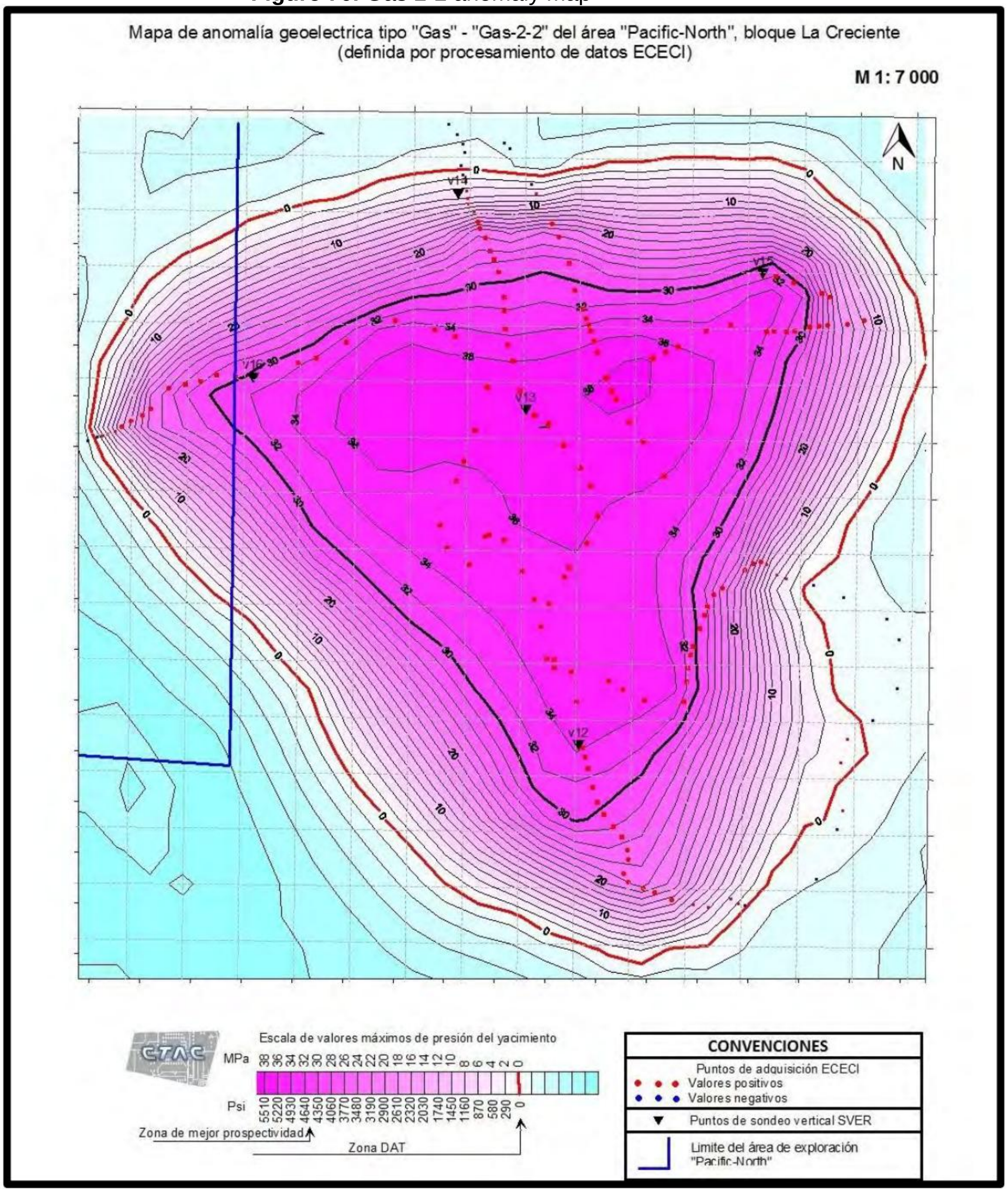
Table 7. Fluids identified stratigraphic level 2 anomalies Gas 2-1

Stratigraphic level number 2		
Layer 1: Gas Free	Layer 2: Free Gas Layer 3: Free Gas	
Depth: 11804 -11890 feet	Depth: 11969 - 12058 feet	Depth: 12090 – 12166 feet
Average thickness: 35 feet	Average thickness: 19.7 feet	Average thickness: 27.3 ft
Approximate pressure: 36 Mpa	Approximate pressure: 35 Mpa	Approximate pressure: 35.2 Mpa

Gas 2-2 Anomaly. For this structure, the points were located at the limits of the same, having the points V12, V13, V14, V15, V16 **(Figure** 70), according to the results obtained in the vertical sounding, allows to correlate each point belonging to Gas 2-2 and obtain a vertical profile of the anomaly, which in the case of Gas 2-2, were called Prf3 and Prf4, for their corresponding interpretation.

Figure **70** shows the anomaly map, Gas 2-2, corresponding to a scale of 1:700, and shows the location of the points for taking the vertical soundings.

Figure 70. Gas 2-2 anomaly map

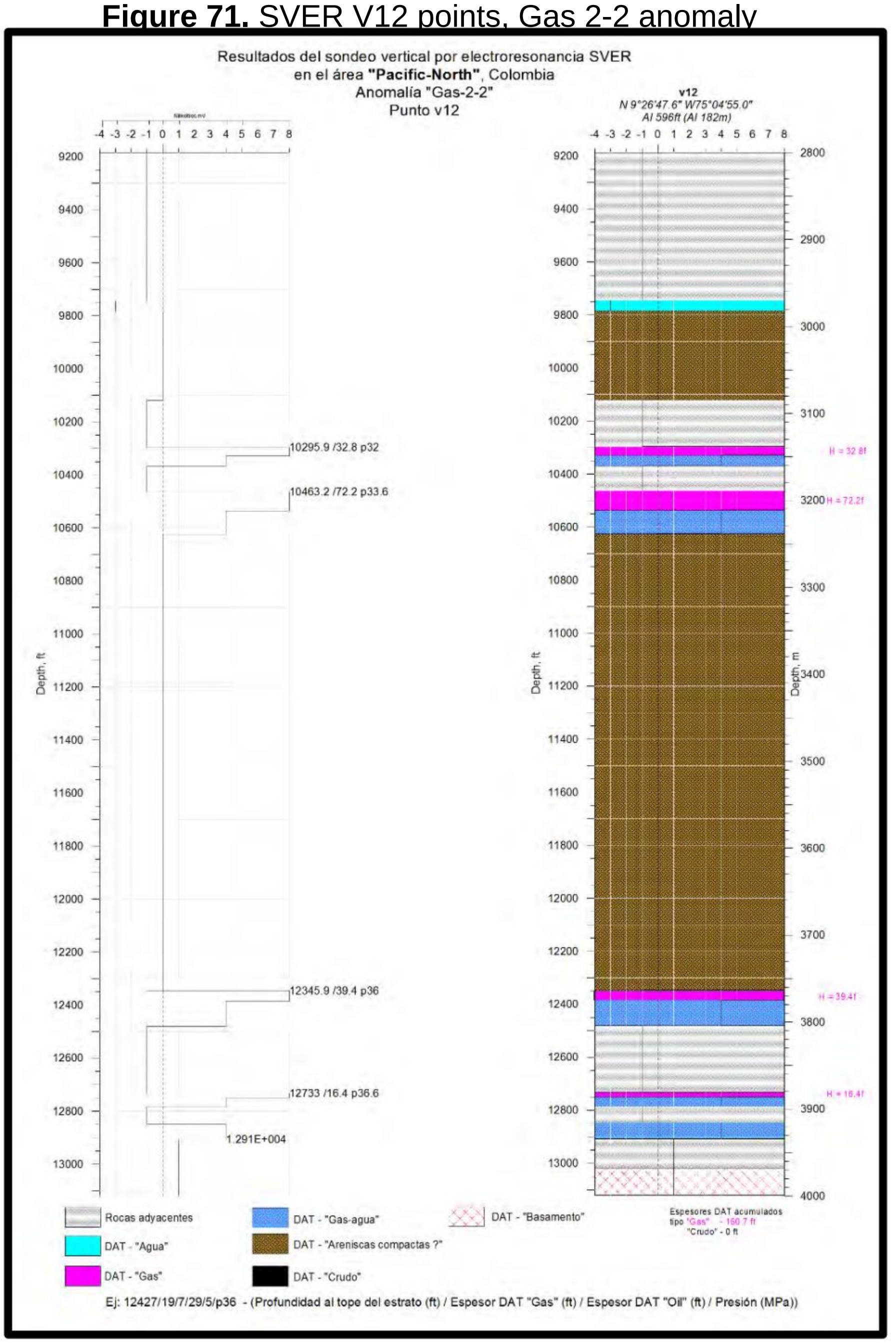


Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Taking each vertical sounding point in each area allows obtaining a vertical image just like Gas 2-1, for Gas 2-2 the same interpretation is made for each vertical sounding, as seen in **Figure 71, Figure**

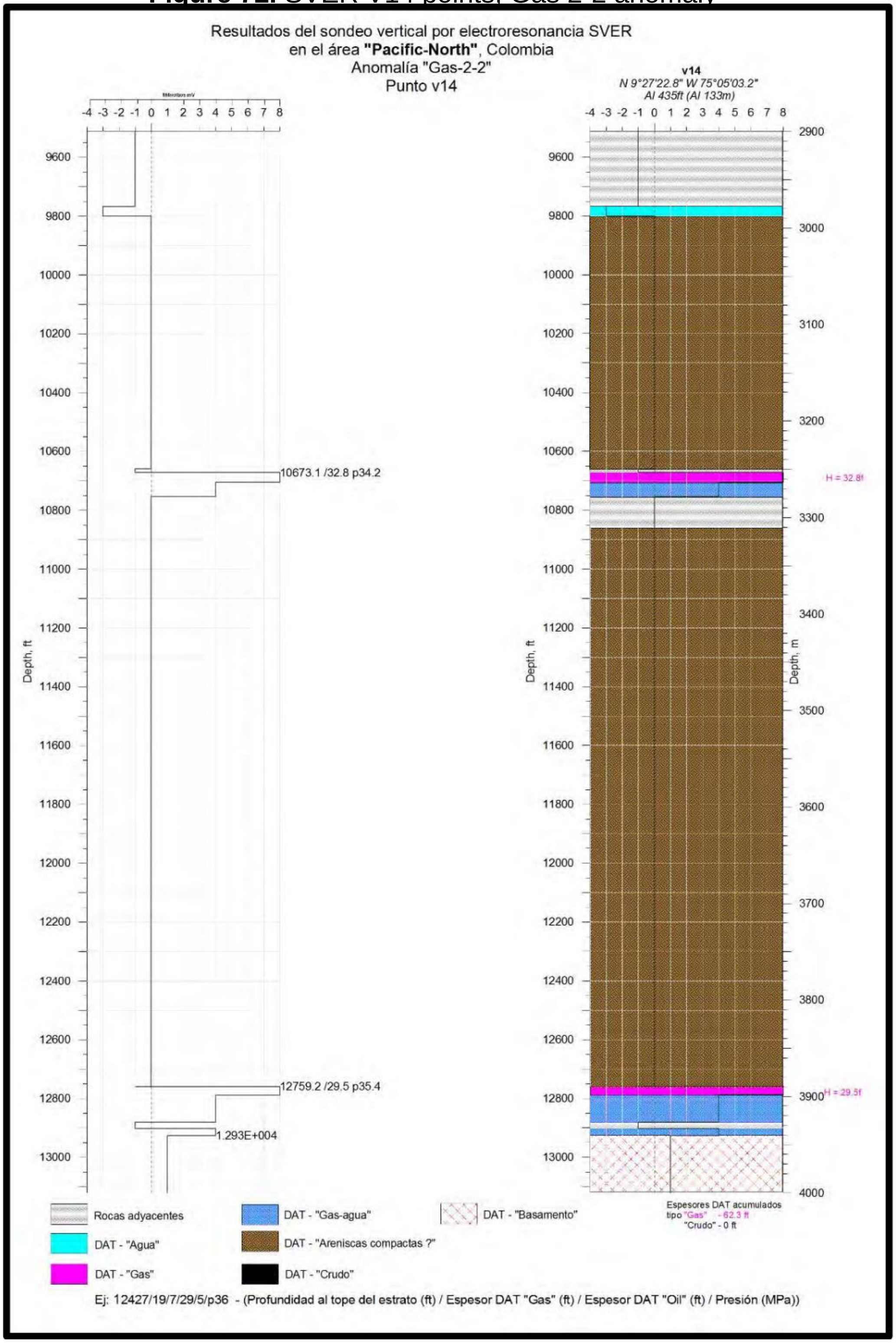
72, Figure 73, corresponding to the vertical sounding point called V12, V13 **(Annex** D), V14, V15 **(Annex** E) and V16, the column on the left corresponds to millivolts (mV), likewise the column on the right allows to interpret according to the value established in column one the presence with depth of fluids such as gas, crude oil and water.

Figure 71. SVER V12 points, Gas 2-2 anomaly



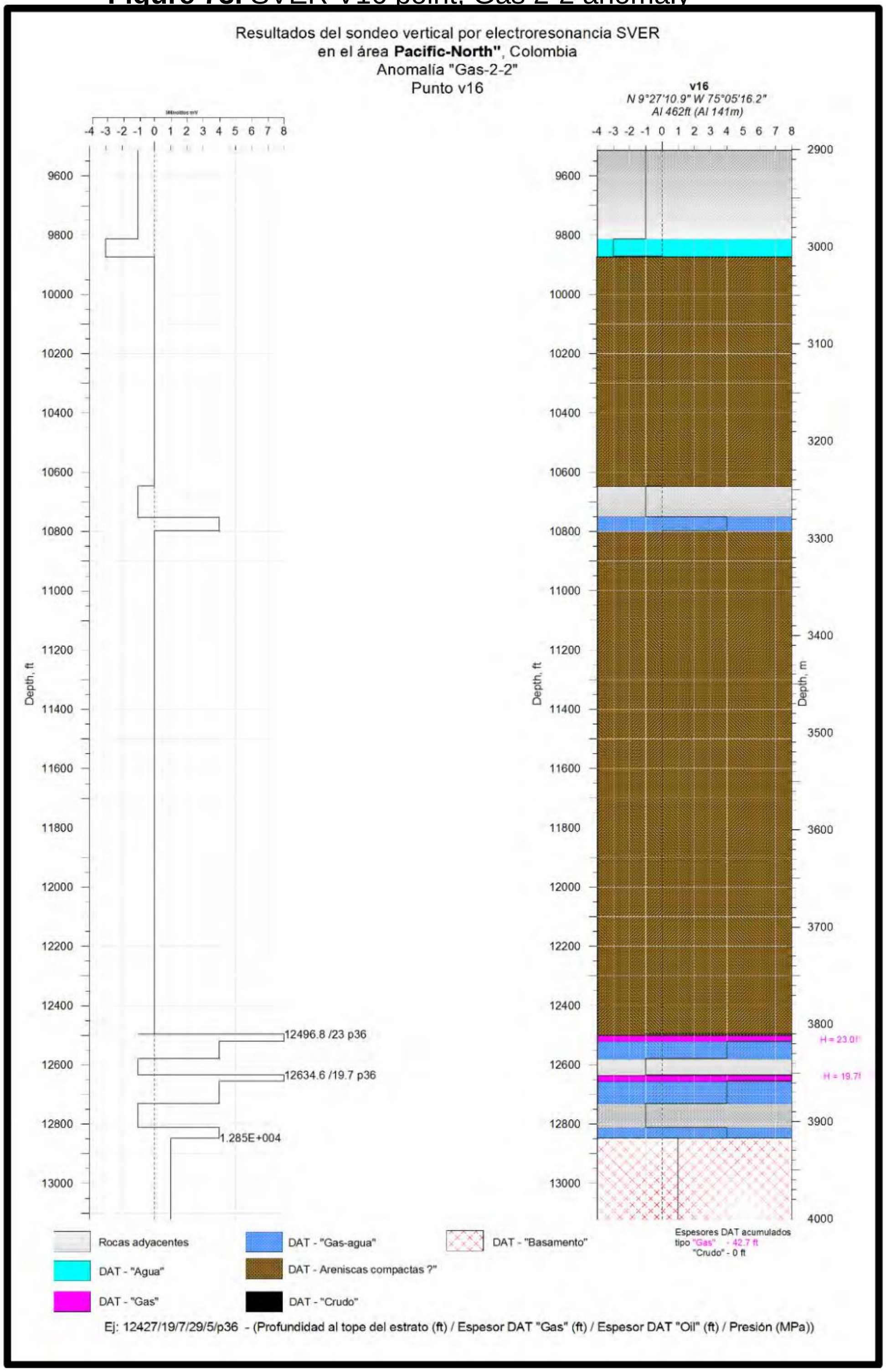
Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.

Figure 72. SVER V14 points, Gas 2-2 anomaly



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.

Figure 73. SVER V16 point, Gas 2-2 anomaly

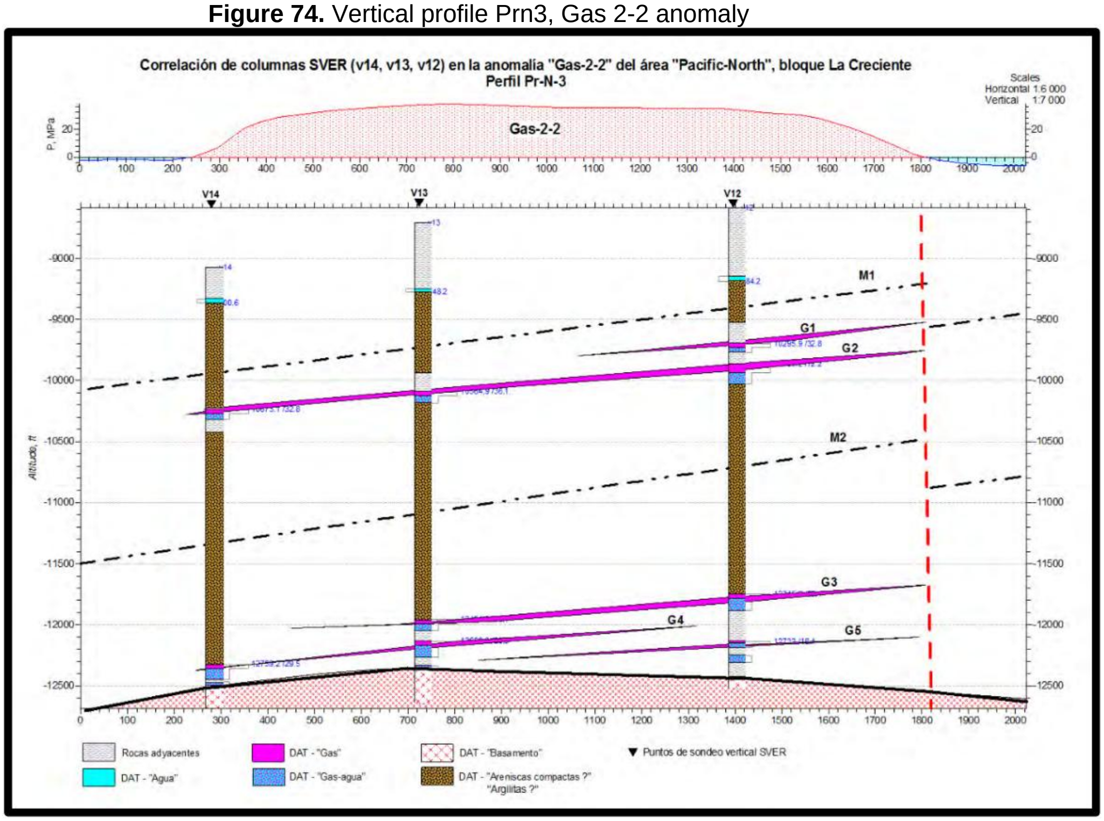


Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.

The union of these vertical sounding points allows generating a profile of the entire area, and as observed in **Figure 74** and **Figure 75,** the unions of these points are intertwined generating the correlation, as in the Gas 2-1 correlation, which for this case the La Creciente Field corresponds to free gas type fluid.

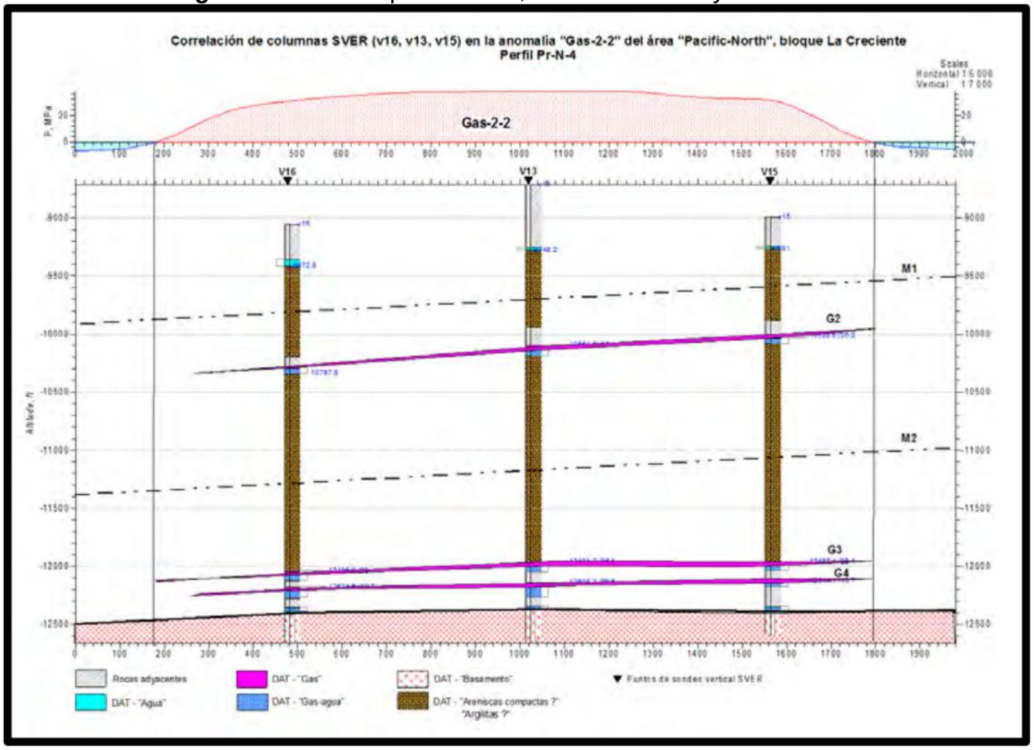
Figure **74** and **Figure 75** show the correlation and union of the points belonging to the North Zone, of the Gas 2-2 zone, the points joined to form this profile correspond to V12, V13, V14, V15, and V16. This profile shows the presence of gas at depths of 10,200 - 10,650 feet and 12,300 - 12,800 feet. It also detects the depth at which the basement is located and its continuity throughout the zone, confirming the high resolution projected by the SVER phase of oil and gas exploration technology (OFT).

Figure 74. Vertical profile Prn3, Gas 2-2 anomaly



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Figure 75. Vertical profile Prn4, Gas 2-2 anomaly



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.

As the Gas 2-1 correlation was carried out, the analysis of the following is based on the identification of the layers of hydrocarbon-type fluids in each zone, so for the Gas 2-2 anomaly, it was characterized as follows in two stratigraphic levels:

Table 8. Fluids identified stratigraphic level 1 anomaly Gas 2-2 Stratigraphic level number

1	
Layer 1 Free Gas Layer 2 Free Gas Depth: 10295 ft Depth:	
10463 – 10673	
Average thickness: 32.8 feet Average thickness: 33.46 feet Approximate	
pressure: 32 Mpa Approximate pressure: 27.12 Mpa Stratigraphic level number 2	
Layer 1 Free Gas Layer 2 Free Gas Depth: 12345 – 12496	
Depth: 12608 – 12759 feet	feet
Average thickness: 26.92 Average thickness: 22.96	
Approximate pressure: 28.8 Mpa Approximate pressure: 36.24 Mpa	

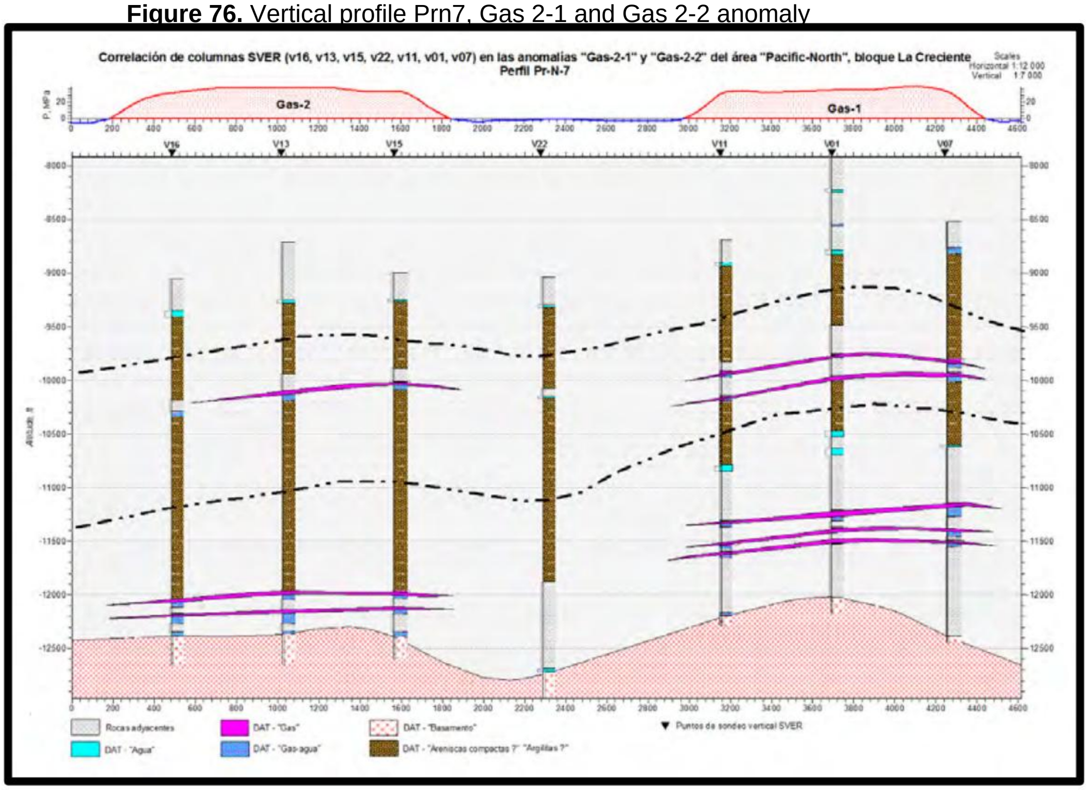
Similarly, in “Gas 2-1”, two stratigraphic levels were detected here. The general inclination of the strata is northeasterly dipping to the northwest.
The maximum values of probable accumulated thicknesses of the “Gas” type DAT were detected in the southern part of the anomaly in areas close to the V12 survey point.

The basement rocks were identified at approximate depths of 12,910 feet. As the points were joined together to make the vertical profiles, the average accumulated thicknesses and approximate pressures were calculated. Using “Gas2-1” and “Gas 2-2”, a vertical section was drawn along the profile called PrN-7.

An anticlinal structural feature stands out in the limits of “Gas-1”. The anticlinal structure can be traced to the top of the basement.

As mentioned Gas 2-1, between the Gas 2-1 and Gas 2-2 anomalies, point V22 was moved, this point was taken between the two anomalies to generate a dotted line that joins these two anomalies and correlate the information obtained in a single profile, as shown in **Figure 76.**

Figure 76. Vertical profile Prn7, Gas 2-1 and Gas 2-2 anomaly



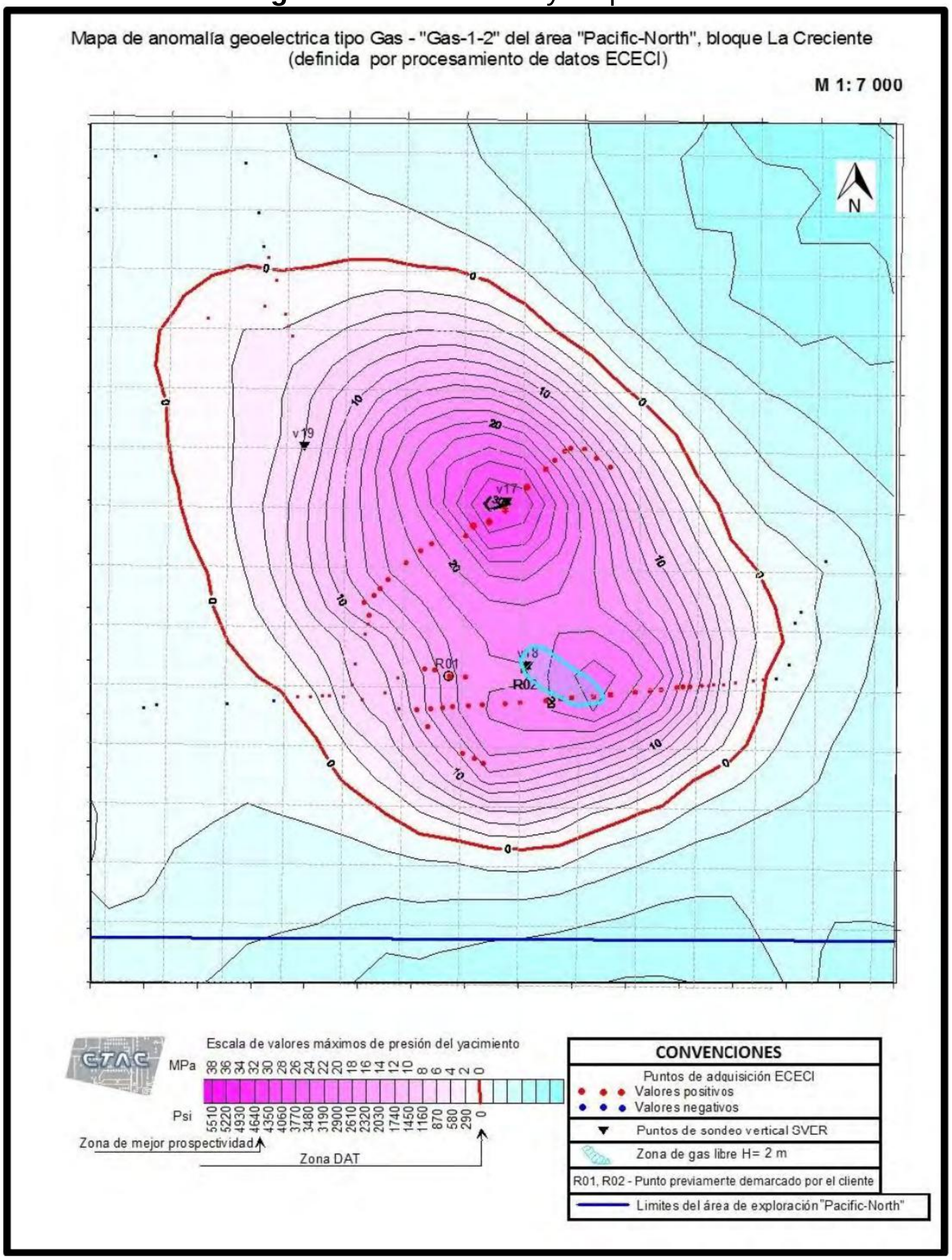
Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

The Prn7 profile shows that between Gas 2-1 and Gas 2-2, it is interpreted that there is a zone with faulting characteristics, which means that these two zones will be separated. Another important aspect is to see the correlation that exists between these zones, which allows us to generate that there is a correlation in the layers in which the fluids are located, as well as the continuity that exists in the basement along the seven points that were taken.

Gas 1-2 Anomaly. The points were located at the limits of the same, having the points V17, V18 and V19 **(Figure** 77), according to the results obtained in the vertical sounding, allowing to correlate each point belonging to Gas 2-2 and obtain a vertical profile of the anomaly, which in the case of Gas 1-2, were called Prf5, for its corresponding interpretation.

Figure **77** shows the Gas 1-2 anomaly map, corresponding to a 1:7000 scale, and shows the location of the points for taking the vertical soundings.

Figure 77. Gas anomaly map 1-2

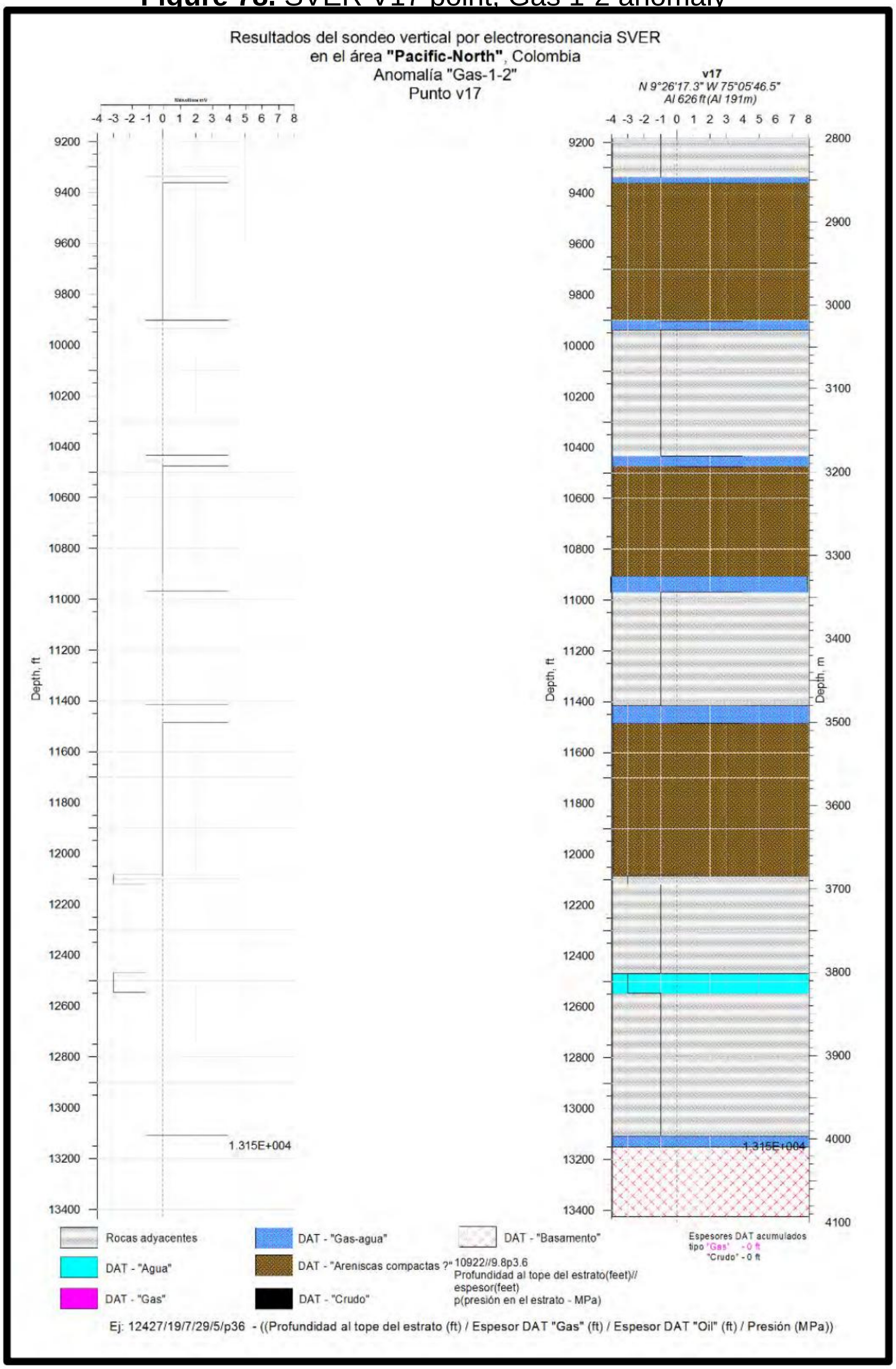


Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

As in the previous anomalies, each vertical sounding point allows obtaining a vertical image of the depth, identifying mainly fluids such as gas, oil and water, contacts of these fluids, certain lithological material and finally the depth at which the basement is located.

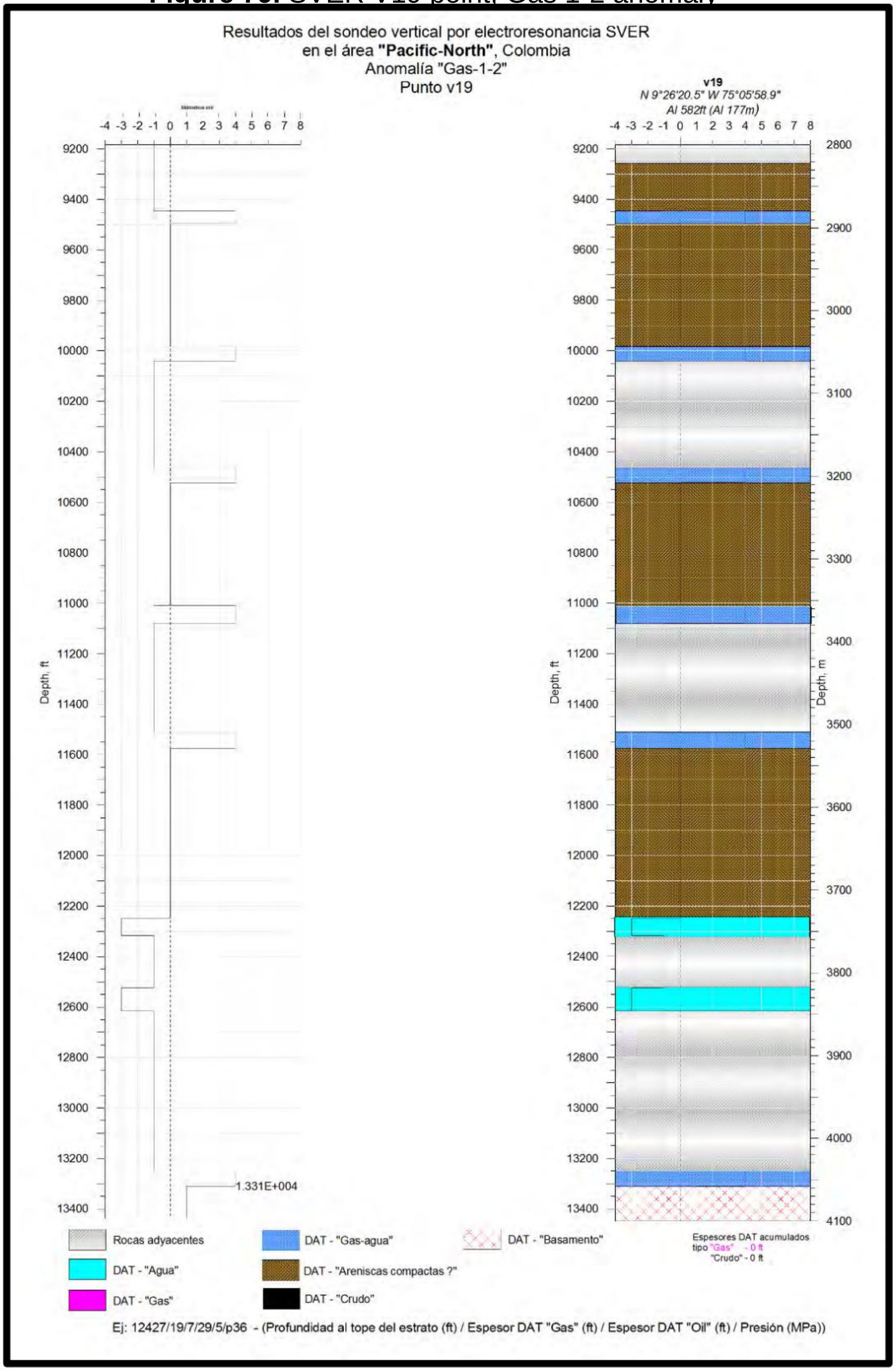
This is why for each point there will be an adequate correlation, as observed in **Figure 78 and Figure 79** corresponding to the vertical sounding point called V17, V18 **(Annex** F) and V19, the column on the left corresponds to its reading in millivolts (mV), likewise the column on the right side allows to interpret according to the value established in column one the presence with depth of fluids such as gas, crude oil and water.

Figure 78. SVER V17 point, Gas 1-2 anomaly



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Figure 79. SVER V19 point, Gas 1-2 anomaly



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

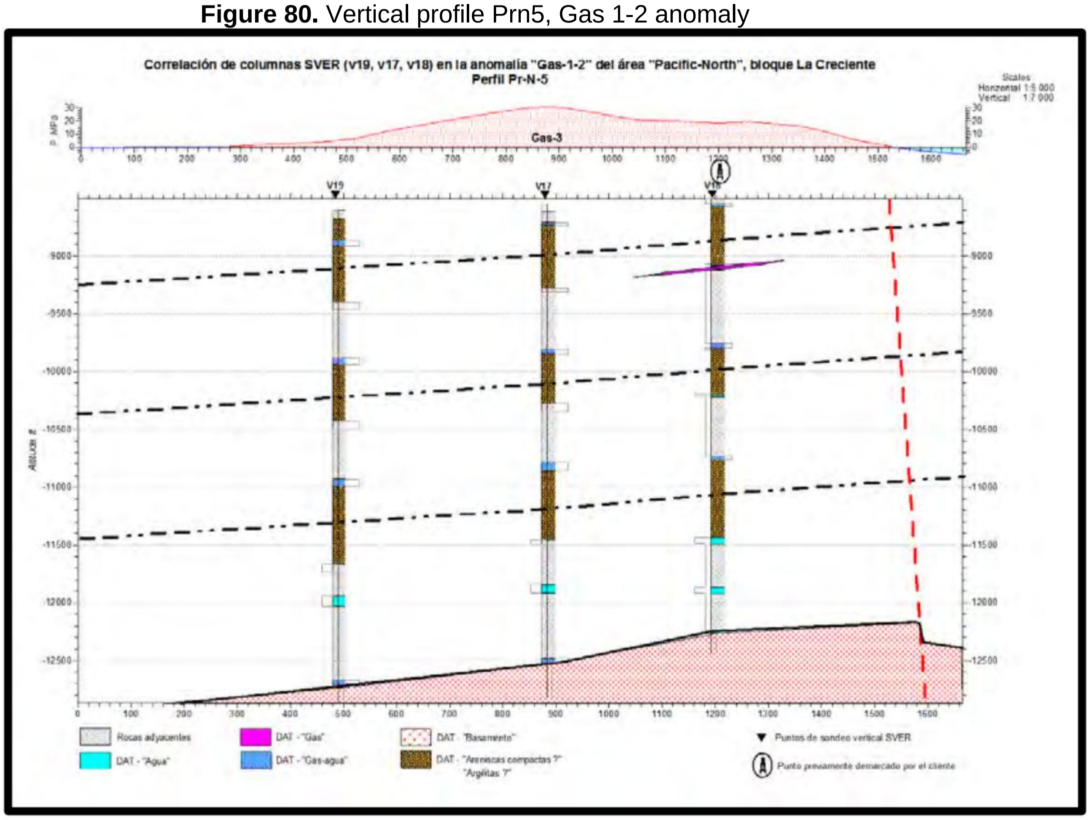
The vertical sounding points in each area, as in the other anomalies, obtained the vertical image of the depth, indicating the gas-water contacts if there are any, determining lithological material and finally the depth at which the basement is located.

As in Gas 2-1, as the main zone of the northern zone, for the Gas 1- zone
2 the same interpretation is carried out for each vertical sounding, as seen in **Figure 80,** corresponding to the previous sounding point.

For Gas 2-1, located in the western part of the northern area, the results of Phase 3 of SVER show that this area is one of the lowest in terms of the strength with which the anomaly was identified, since the frequency was very weak but nevertheless presents the presence of hydrocarbon-type fluids.

For **Figure 80,** the SVER points called V17, V18 and V19 make up the Prn 5 profile, the only area with presence presented a depth of 9,751.4 feet, this area has a net thickness of 6.6 feet and approximate pressure of 32 Mpa, in this area it is worth noting that a well is projected to achieve successful drilling.

Figure 80. Vertical profile Prn5, Gas 1-2 anomaly



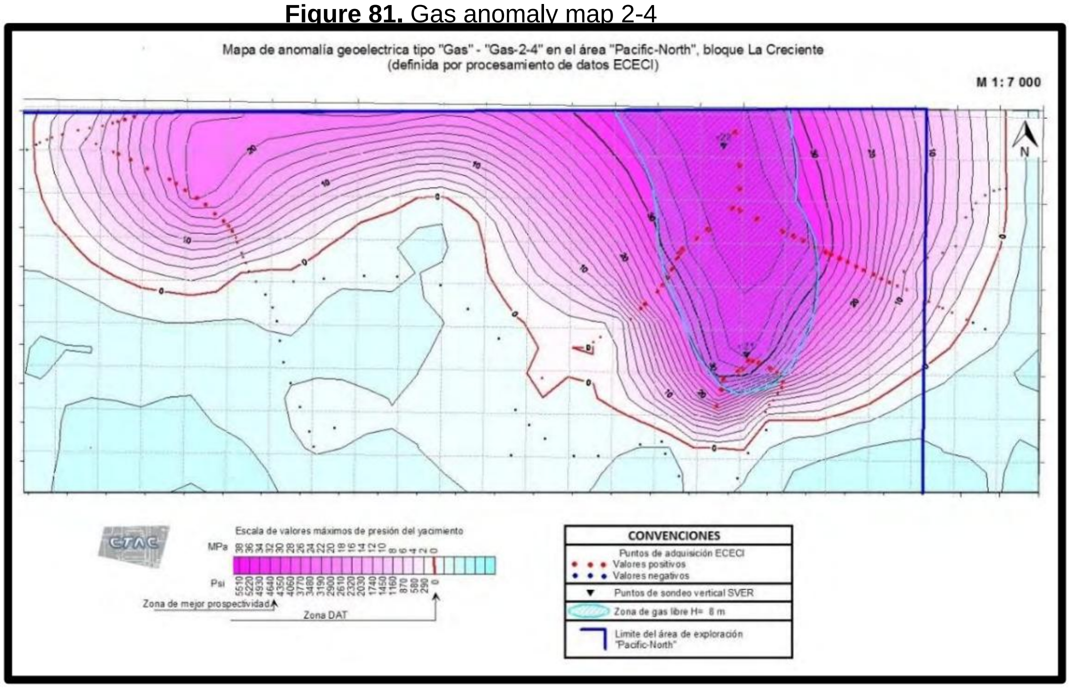
Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Gas 2-4 Anomaly . For the Gas 2-4 structure, it was not initially possible to identify this area in phase 1 of satellite spectrography; however, during the development of the second phase corresponding to Phase 2 of ECECI, this anomaly was discovered, with the limitation that the area that had been initially estimated did not allow the anomaly to be modelled in its entirety, since the corresponding area no longer belongs to the operating company's block but to another company.

Likewise, it was decided to carry out the Gas 2-4 study in order to obtain a characterization of the area to generate a concept for the company of possible exploratory projects in the future.

Figure **81** indicates part of the presence of Gas 2-4, located in the northern part of the La Creciente Field, located in the department of Sucre, according to the color trend of the anomaly, it presents a pinkish hue belonging to the presence of free gas hydrocarbon type fluid.

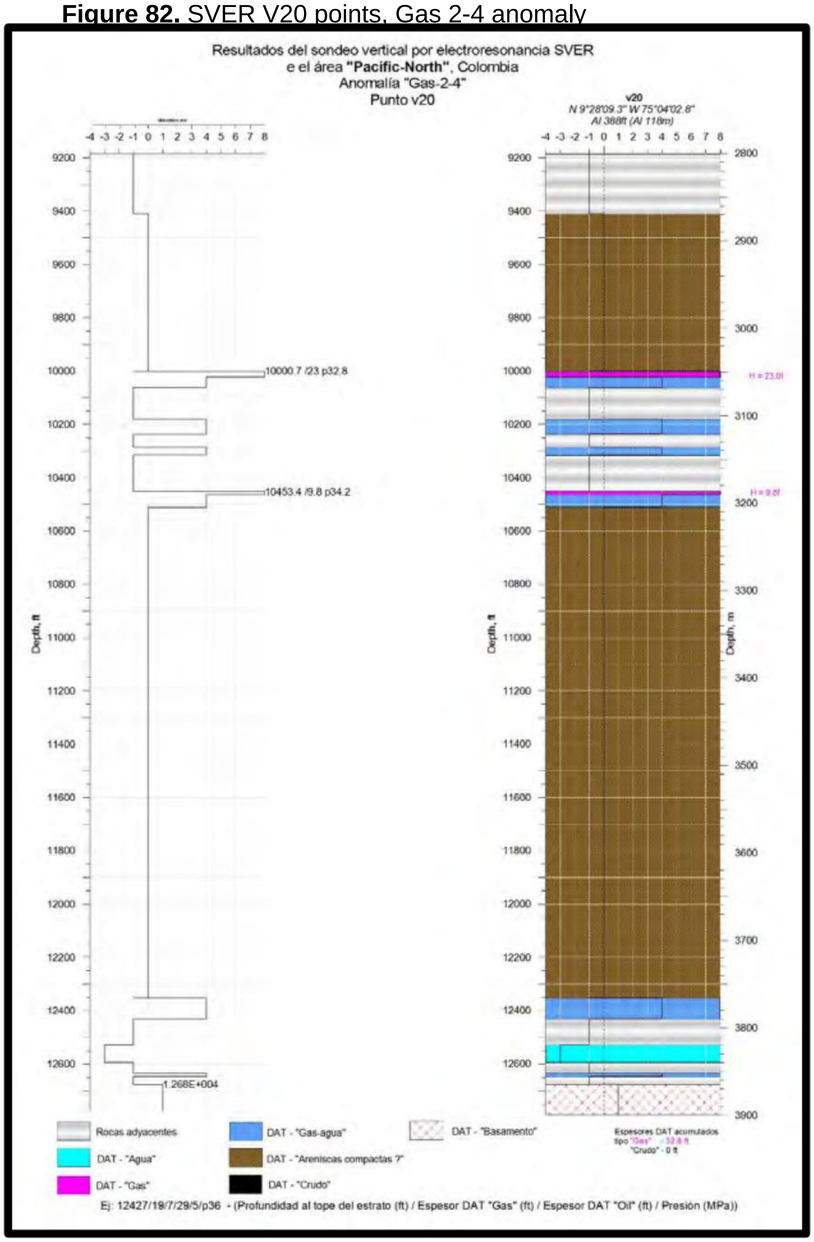
Figure 81. Gas anomaly map 2-4



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Vertical soundings in the areas found allow obtaining a vertical image of the depth, identifying mainly fluids such as gas, oil and water, contacts of these fluids, certain lithological material and finally the depth at which the basement is located. As can be seen in **Figure 82** corresponding to the vertical sounding point called V20 and V21 **(Annex** G), The column on the left corresponds to its reading in millivolts (mV), likewise the column on the right allows to interpret according to the value established in column one the presence with depth of fluids such as gas, crude oil and water.

Figure 82. SVER V20 points, Gas 2-4 anomaly



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

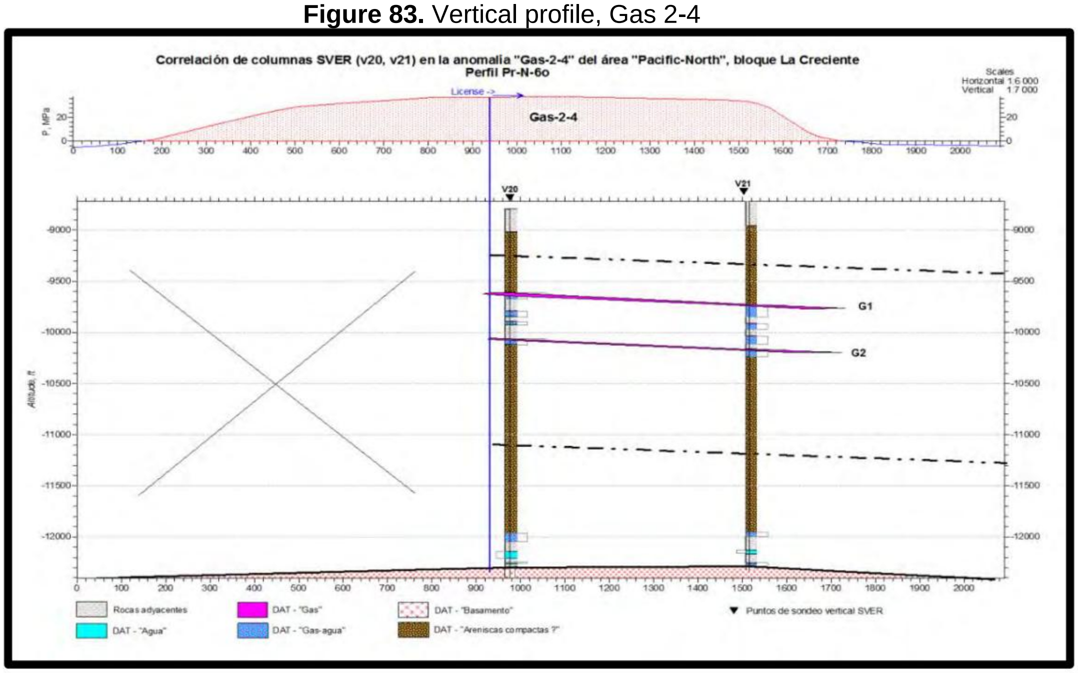
The union of these vertical sounding points allows generating a profile of the entire area of the structure, and as observed in Figure **83,** the union of these points is intertwined generating the correlation, just as in the GAS correlation.

2-1, which in this case the La Creciente Field corresponds to free gas type fluid.

Figure **83** shows the correlation and union of the points belonging to the northern area of Gas 2-2. The points joined to form this profile correspond to V20 and V21. This profile shows the presence of gas at depths 10,000 - 10,200 and 10,453 - 10,627. It also shows the depth at which the basement is located and its continuity throughout the area, confirming the high resolution projected by Phase 3 SVER of the oil and gas exploration technology (OFT).

In **Figure 83,** approximately half of the anomaly is shown corresponding to the part of land awarded to the company by the Colombian state, the other part belongs to the area of the neighboring company.

Figure 83. Vertical profile, Gas 2-4



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Table 9. Fluids identified stratigraphic level 1 anomaly Gas 2-4

Stratigraphic level number 1	
Layer 1 Free gas Layer 2 Free gas	
Depth: 10000.7 –	Depth: 10453.4 – 10627.2 10200.8 feet feet
Average thickness: 18 feet Average thickness: 13.1 feet Approximate pressure:	
32.8 Mpa Approximate pressure: 34.2 Mpa	

Phase 3 SVER results for the South Zone polygon #3. For the South Zone, the study will be based on the Oil 4-1 structure. For each zone, between 2 and 6 vertical survey data collection points will be established. It should be noted that this data collection must be carried out with the generation equipment fixed to the surface.

Within the 22 points established for data collection, the following 6 points were assigned to the Northern Zone:

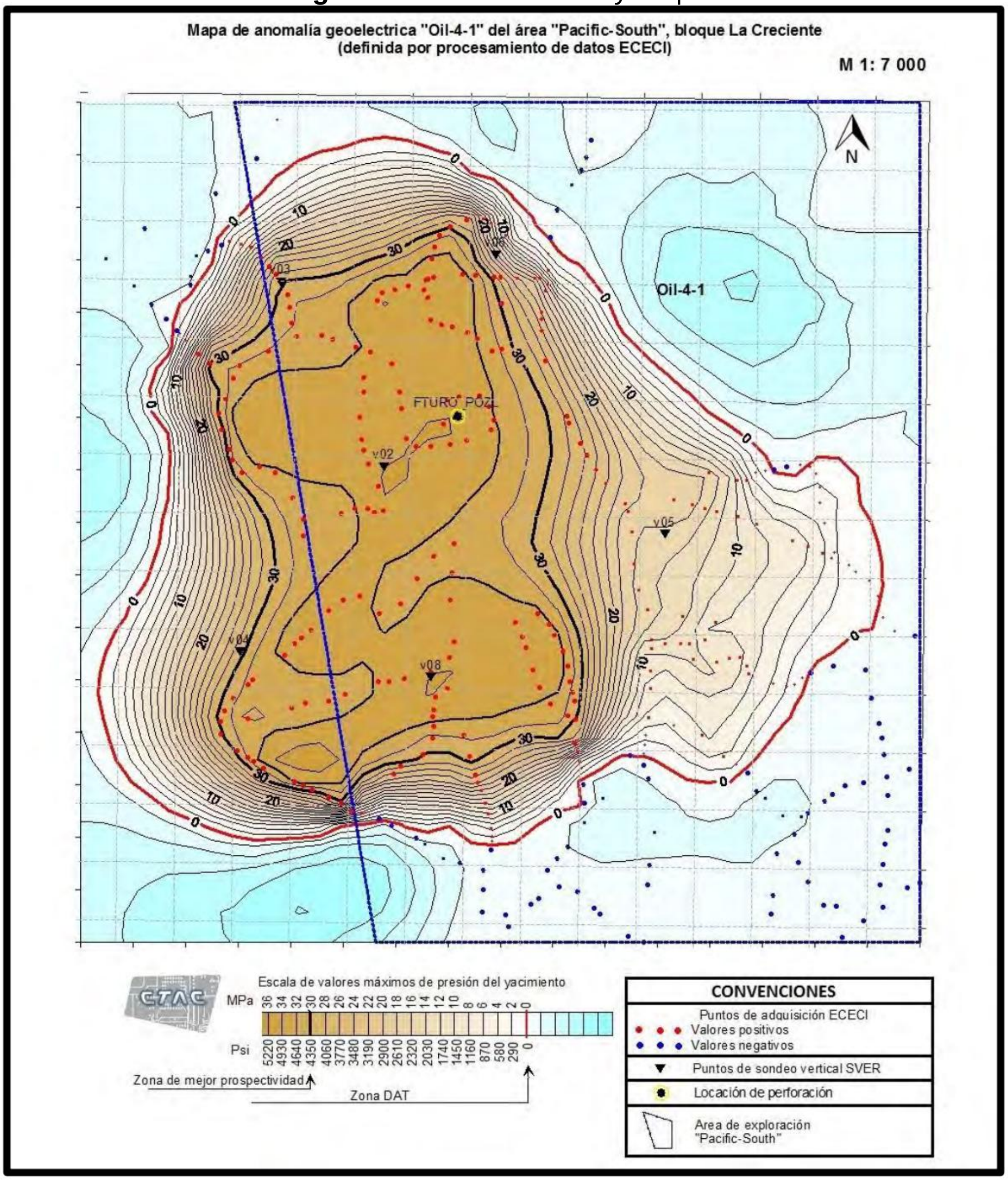
Table 10. SVER Points Southern Zone in Oil 4-1 Anomaly Anomalous

Zone	SVER Points
OIL 4-1	V02, V03, V04, V05, V06, V08

As the southern area is analyzed, OIL 4-1 corresponds to a petroleum hydrocarbon-type fluid structure, since both in Phase 1 of a spectrographic image and Phase 2 of ECECI the presence of oil was confirmed in it, and for this reason the hue is brown-coffee. The results of the geoelectric study determined that the area is around 1,312 km2 .

The Oil 4-1 structure is represented by **Figure 84,** in which you can see the location of the field points for Phase 3 corresponding to the SVER point, called V02, V03, V04, V05, V06, V08.

Figure 84. Oil 4-1 anomaly map

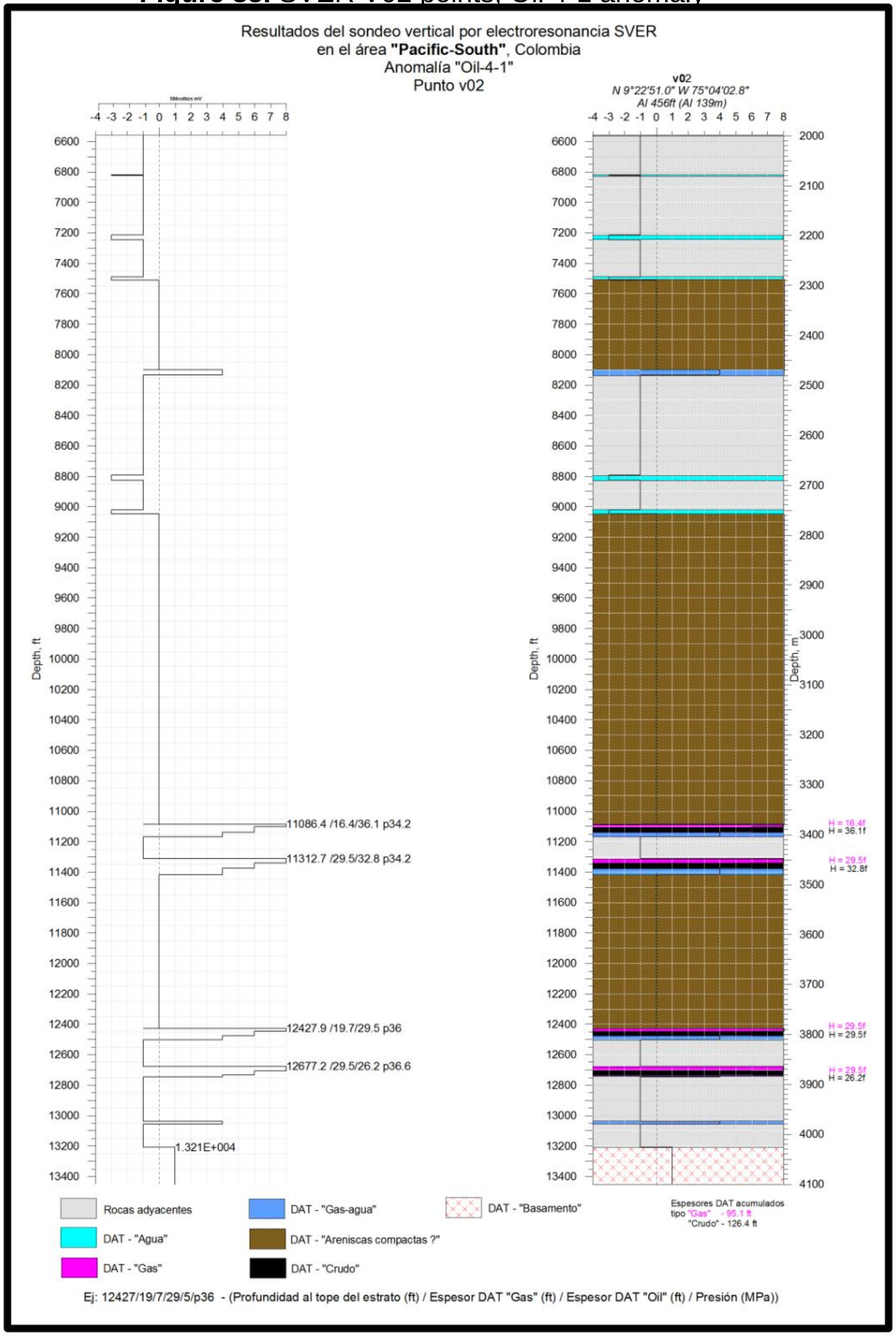


Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

The vertical sounding points in the areas, as seen in **Figure 85,** **Figure 86** and **Figure 87** corresponding to the vertical sounding point called V02, V03 **(Annex** H), V04, **V05 (Annex** I), V06 and **V08 (Annex** J), the left column corresponds to its reading in millivolts (mV), likewise the column of

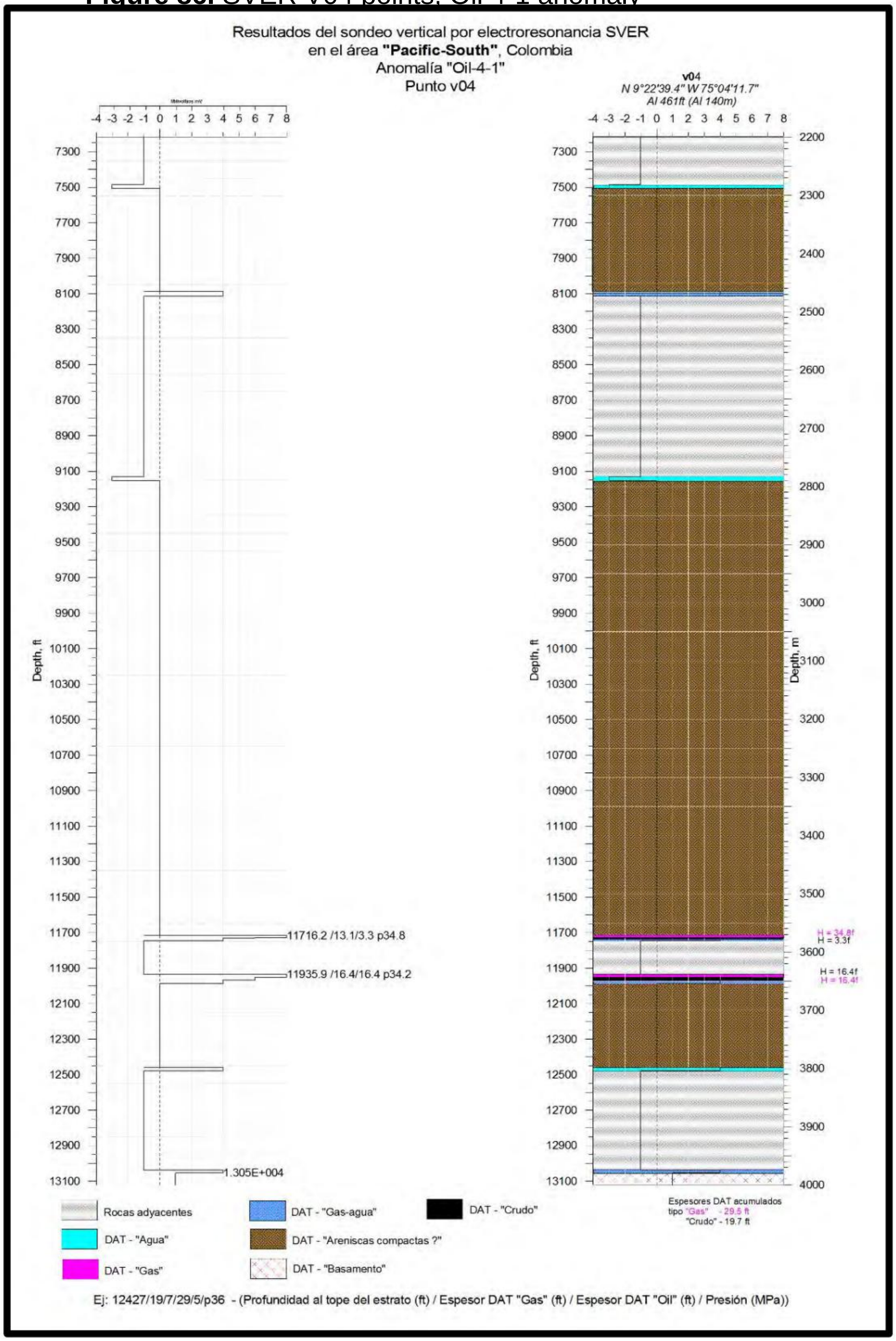
The right side allows the interpretation of the presence of fluids such as gas, crude oil and water at depth according to the value established in column one.

Figure 85. SVER V02 points, Oil 4-1 anomaly



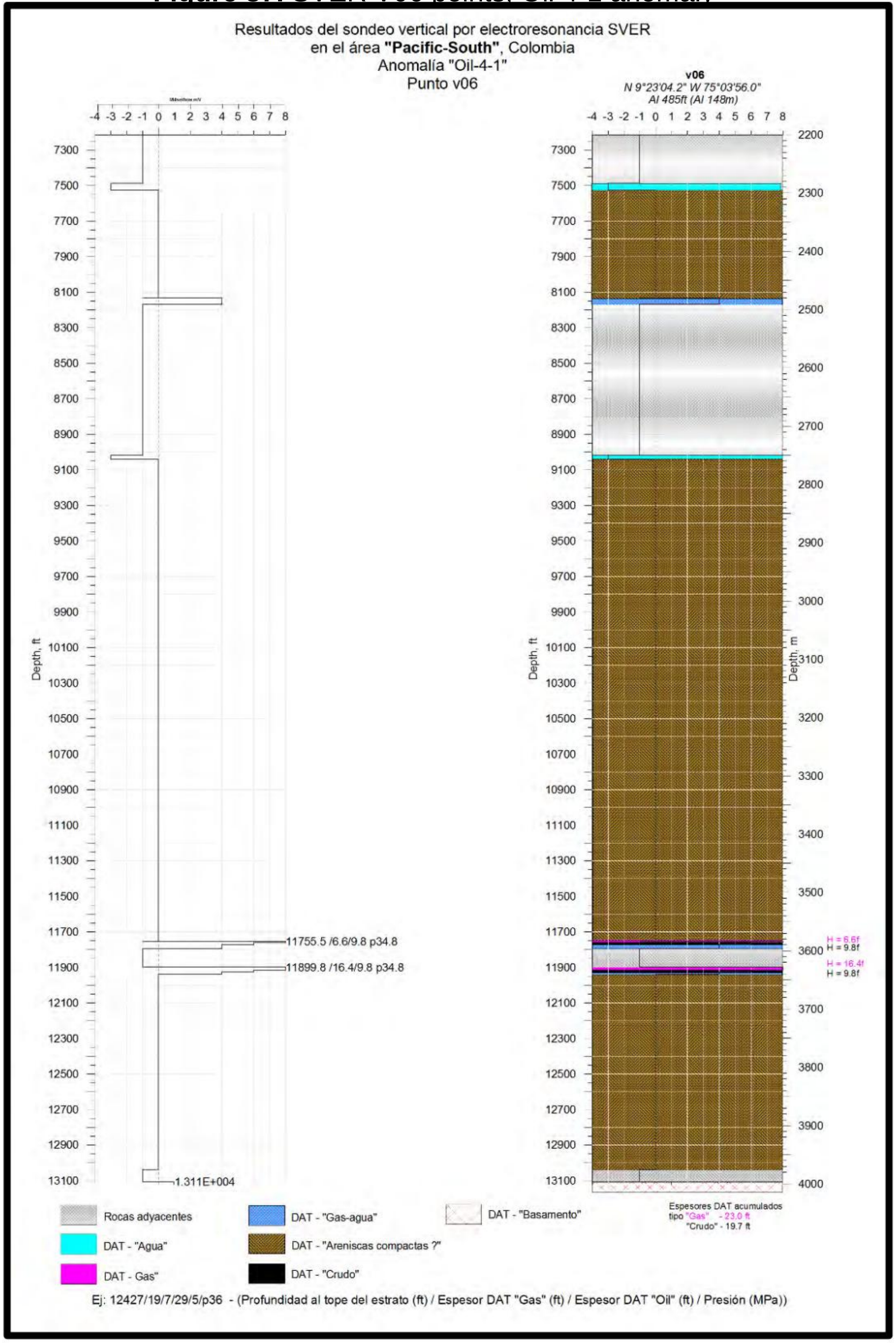
Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Figure 86. SVER V04 points, Oil 4-1 anomaly



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Figure 87. SVER V06 points, Oil 4-1 anomaly

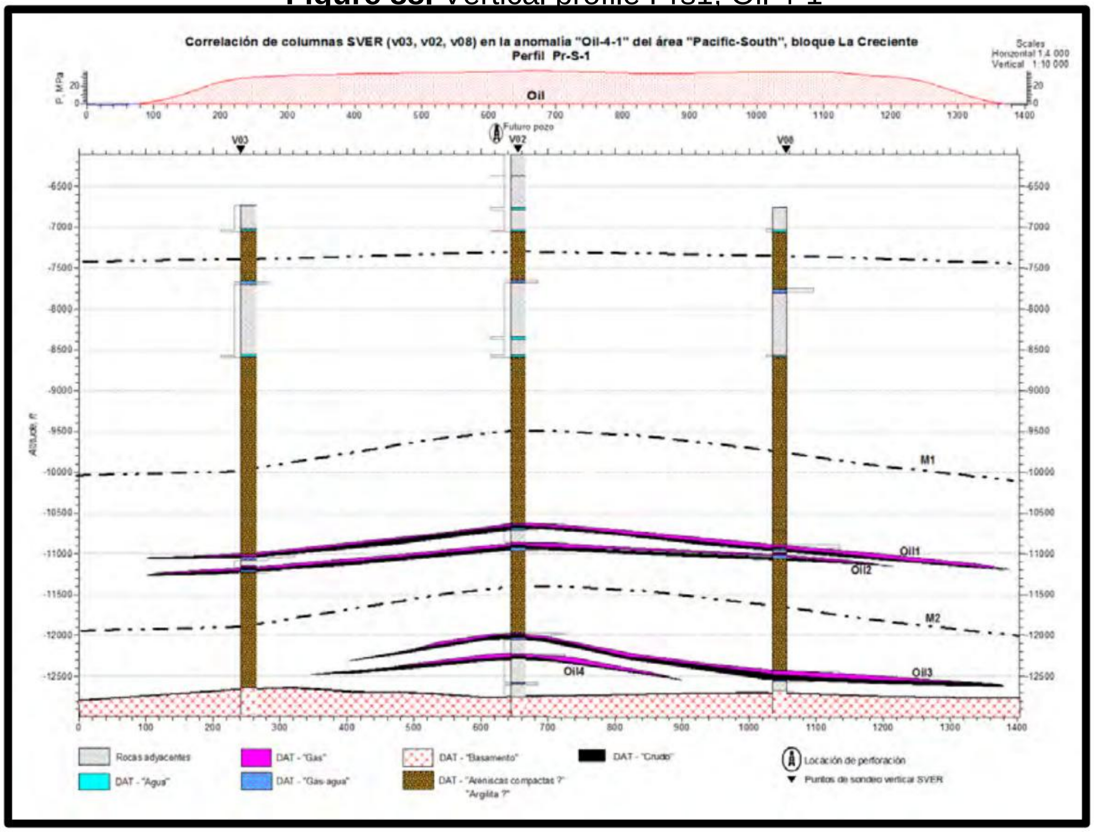


Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.

At the time the work was carried out in the study area, the drilling and location of a drilling well was being planned in the central part. These were detected by the oil resonance frequencies. According to the geoelectrical anomaly, the reservoir on which the structure is located corresponds to an oil reservoir with a gas layer.

Three vertical correlation cuts were drawn in the area, along the profiles called PrS1, PrS2 and PrS3. The closest drilling point to the projected well is V02. This point is located 140 m to the south-west of the projected well. The results of the drilling show that two different stratigraphic levels are located at this point, levels in which the presence of gas-crude oil type DAT is evident, as indicated in **Figure 88.**

Figure 88. Vertical profile Prs1, Oil 4-1



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

At the upper level, two layers of crude oil and natural gas were detected:

Table 11. Fluids identified stratigraphic level 1 anomaly Oil 4-1

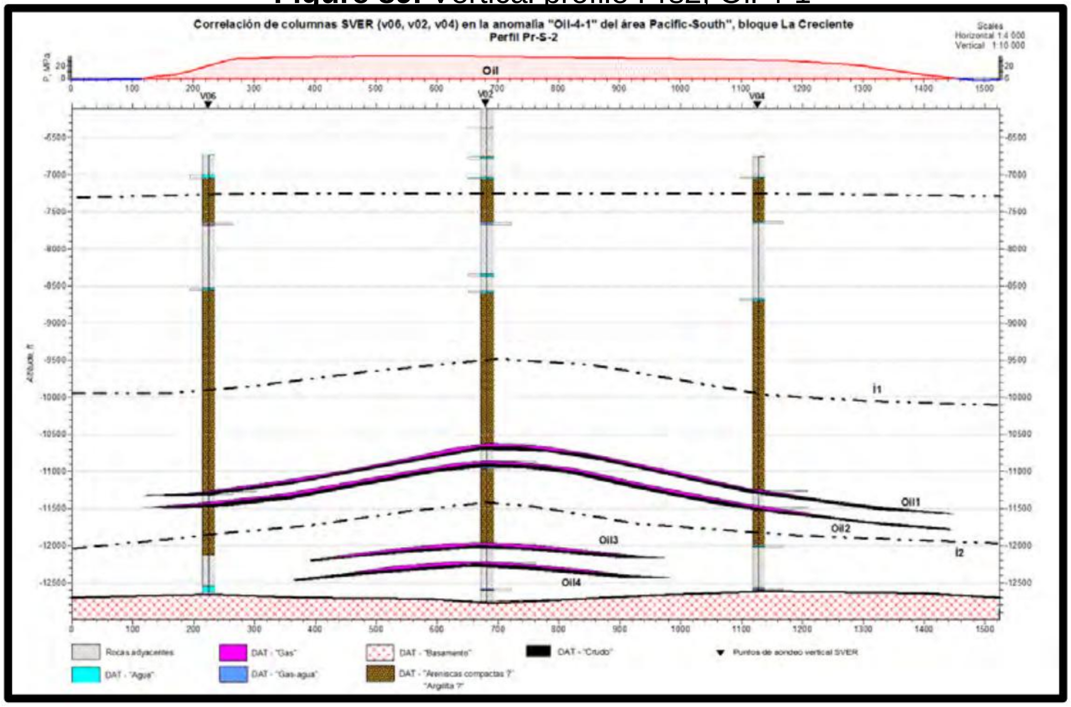
Stratigraphic level number 1	
Layer 1 Gas condensate	Layer 2 Raw
Depth: 11086 – 11496 feet	Depth: 11,102 – 11,525 feet
Average thickness: 29.5 feet Average thickness: 30.2	
Approximate pressure: 34.2 Mpa Approximate pressure: 34.07 Mpa	
Stratigraphic level number 1	
Layer 1 Gas condensate	Layer 2 Raw
Depth: 11312 – 11450 feet Average	Depth: 11342 – 11463 feet
thickness: 21.3 feet Average thickness: 29.5	
Approximate pressure: 34.2 Mpa Approximate pressure: 34.2 Mpa	

Table 12. Fluids identified stratigraphic level 2 anomaly Oil 4-1 Stratigraphic level number

2	
Layer 1 Gas condensate Layer 2 Crude oil Depth: 12,427	
ft Depth: 12,447 ft Average thickness: 19.7 ft Average thickness: 29.5 ft	
Approximate pressure: 36 Mpa Approximate pressure: 36 Mpa	
Stratigraphic level number 2	
Layer 1 Gas condensate Layer 2 Crude oil	
Depth: 12677 – 12903 ft Average	Depth: 12706 – 12962 feet
thickness: 44.25 ft Average thickness: 43 ft Approximate pressure: 36.9	
Mpa Approximate pressure: 37.2	Mpa

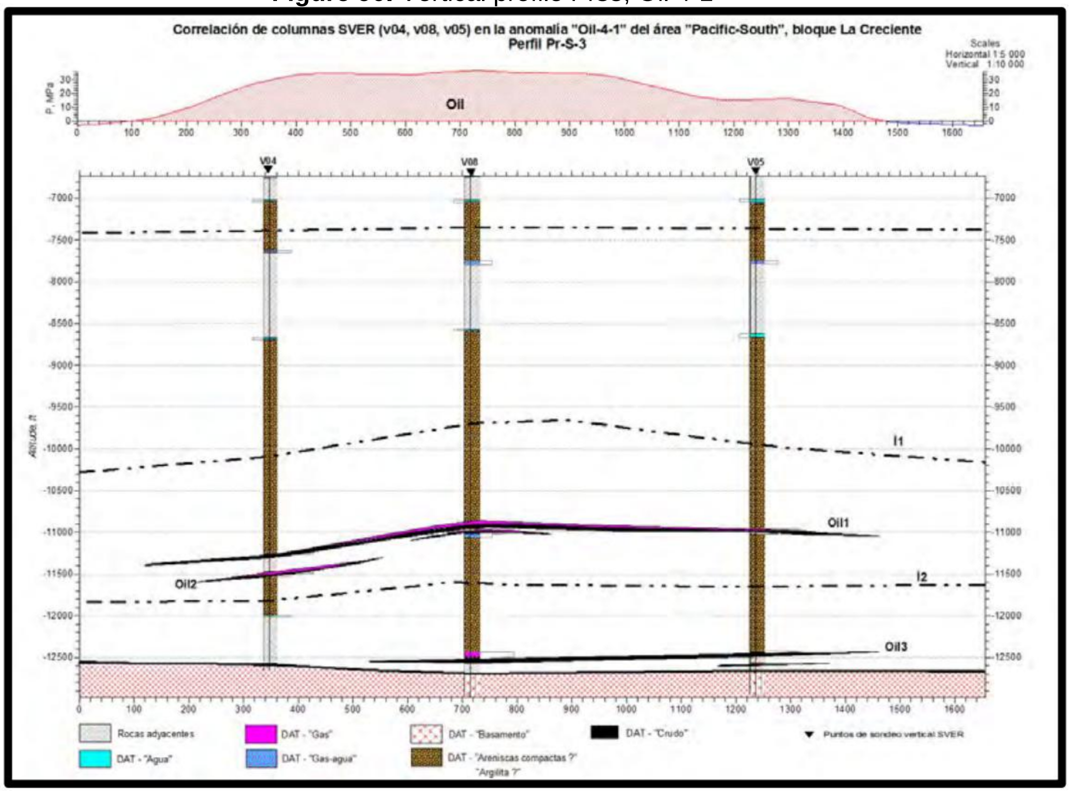
Three vertical correlation cuts were drawn in the area, as the previous profile for the next two called Pr-S2 and Pr-S3. The closest drilling point to the projected well is V02. This point is located 140 m to the South-West of the projected well. The results of the drilling show that at this point two different stratigraphic levels are located, levels in which the presence of gas-crude type DAT is evident, as indicated in Figure **89** and **Figure 90.**

Figure 89. Vertical profile Prs2, Oil 4-1



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Figure 90. Vertical profile Prs3, Oil 4-1



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

Table 13. Fluids identified stratigraphic level 1 anomaly Oil 4-1 Stratigraphic level

number 1	
Layer 1 Gas condensate Layer 2 Crude oil	
Depth: 11352 – 11716 feet	Depth: 11394 -17229 feet
Average thickness: 34 feet Average thickness: 10 feet	
Approximate pressure: 34.2 Mpa	Approximate pressure: 34.2 Mpa
Stratigraphic level number 1	
Layer 1 Gas condensate Layer 2 Crude oil	
Depth: 11450 – 11935 feet	Depth: 11463 – 11952 feet
Average thickness: 14.75 feet	Average thickness: 21.3 feet
Approximate pressure: 22.8 Mpa	Approximate pressure 34.2 Mpa

Table 14. Fluids identified stratigraphic level 2 anomaly Oil 4-1 Stratigraphic

level number 2	
Layer 1 Gas condensate	Layer 2 Crude oil (point V05)
Depth: 12903 - 12906 feet	Depth: 12916 – 12962 feet
Average thickness: 34.4 feet	Average thickness: 34.4 feet
Approximate pressure: 36.3 Mpa	Approximate pressure: 36.3 Mpa
Stratigraphic level number 2	
Layer 2 Gas condensate (point V05)	
Depth: 13051 feet	
Average thickness: 6.60 feet	
Approximate pressure: 34.8 Mpa	

Basement rocks were detected at 13,210 ft and traced to 14,760 ft (4,500 m).

5. CORRELATION OF CONVENTIONAL RESULTS WITH RESPECT TO THE RESULTS OF OIL AND GAS SEARCH TECHNOLOGY (OFT)

The development of this chapter is carried out from the analysis made with the results obtained in conventional methods, in contrast to the geological information that exists, in turn this information is related to the information obtained in the oil and gas search technology (OFT), comparing the existing relationship between these methods that allows reinterpreting the

information to be able to generate a study that allows the new characterization of the presence of hydrocarbons in the area to be studied.

Most of the seismic information is confidential and a request was made to obtain it, but it was not possible to obtain it. Therefore, public seismic information was used, which means that a conclusive analysis with the desired high accuracy cannot be carried out. Finally, access was obtained to a structural map of the top of the Ciénaga de Oro Formation, which was provided by the company Pacific Rubiales, which allowed a correlation to be made with the different anomalies found in the oil and gas search technology (OFT).

5.1 STRUCTURAL MAP ANALYSIS

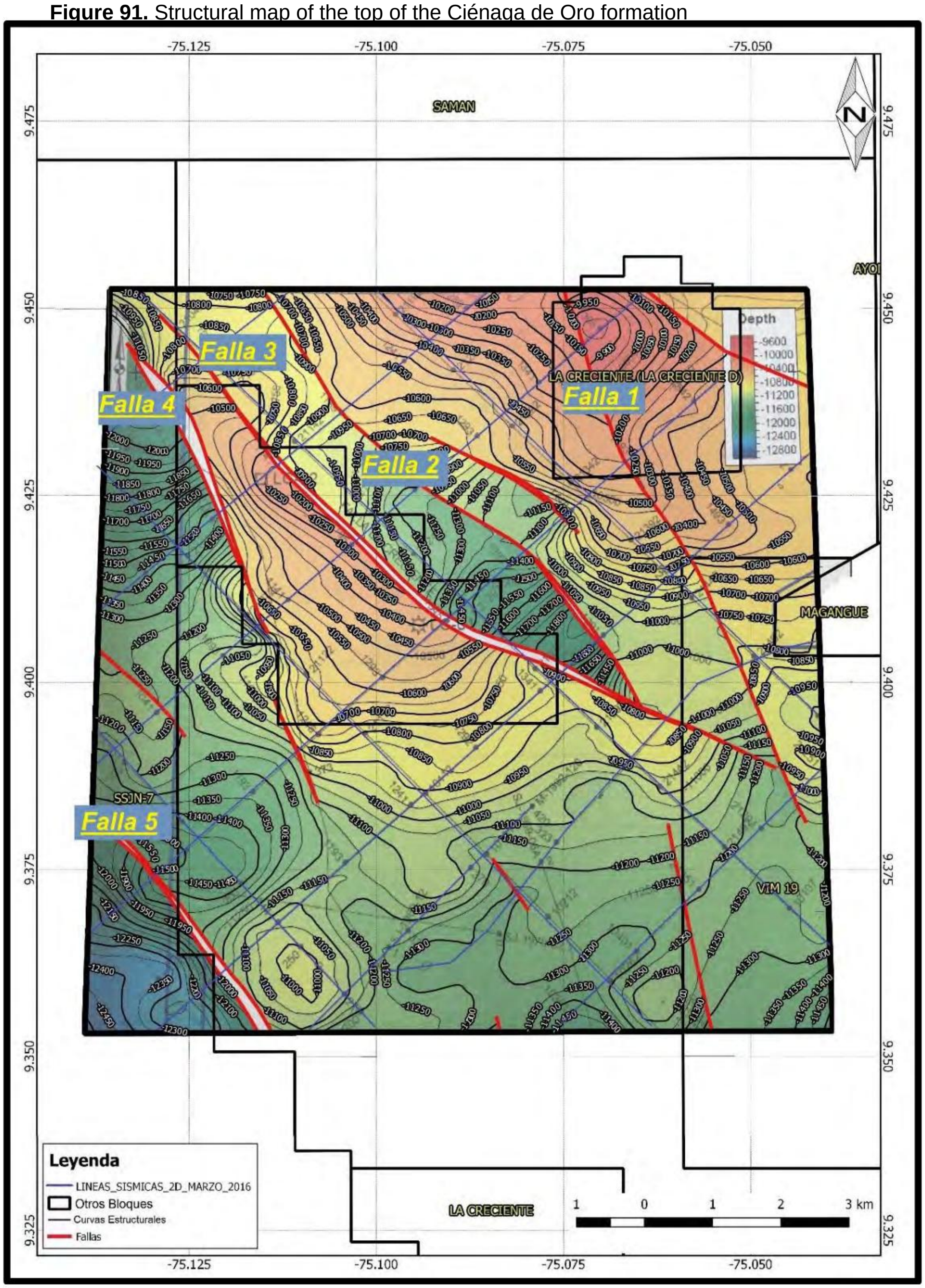
On the structural map at the top of the Ciénaga de Oro formation (see **Figure** 91), the presence of 3 normal faults can be observed that cross the study area with a northwest and southeast direction, generating favorable folds for the accumulation of hydrocarbons. Where the discontinuity of the structural curves due to the faults is observed, these fault jumps are between 300 to 600 feet, considering possible structural closures.

The dip present in the area has a south-west direction, with a regional trend in the south-west block. Fault 3 dips to the north-east and fault 1 dips to the south-west, generating a graben-type structure, causing structural highs in the underlying blocks that are conducive to hydrocarbon accumulation. A “horst” type structure is formed between fault 3 and fault 4, which constitutes the most important structural closure with potential for hydrocarbon accumulation within the studied area.

The structural map shows a color scale at the top right, which by fading colors allows to identify the depth, where the faint red color indicates the highest part called structural high (9,600 to 10,300 feet) to the blue color as the deepest part called structural low (12,200 to 12,800 feet).

For the structural map at the top of the Ciénaga de Oro Formation, two structural highs conducive to the accumulation of hydrocarbons can be seen; the first structural high is located on the flank that rose with respect to fault 3 and the second structural high is located on the flank that rose with respect to fault 1.

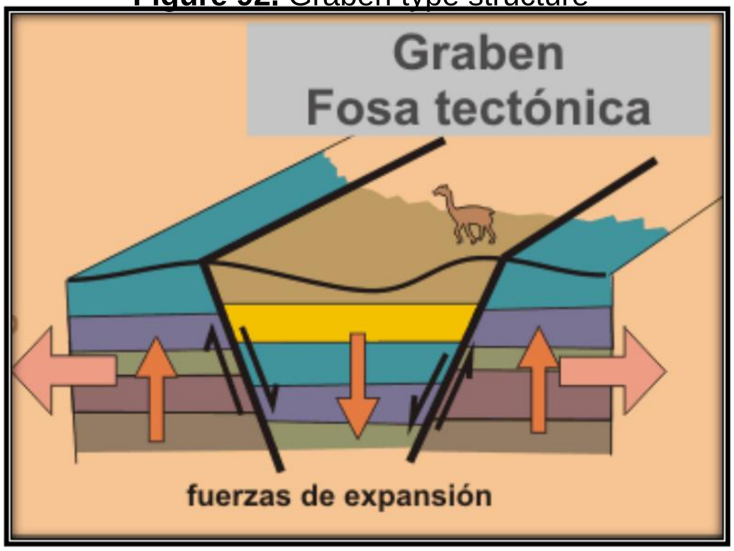
Figure 91. Structural map of the top of the Ciénaga de Oro formation



Source: Analysis of Pacific Rubiales seismic results, modified by the authors.

A graben-type structure (tectonic trench), as illustrated in **Figure 92,** is the set of two parallel normal faults with opposite inclination in an expansive tectonic environment, for this reason the central sector moves relatively downwards with respect to the flanks. Generally, younger rocks outcrop inside a tectonic trench as outside the system29 .

Figure 92. Graben-type structure

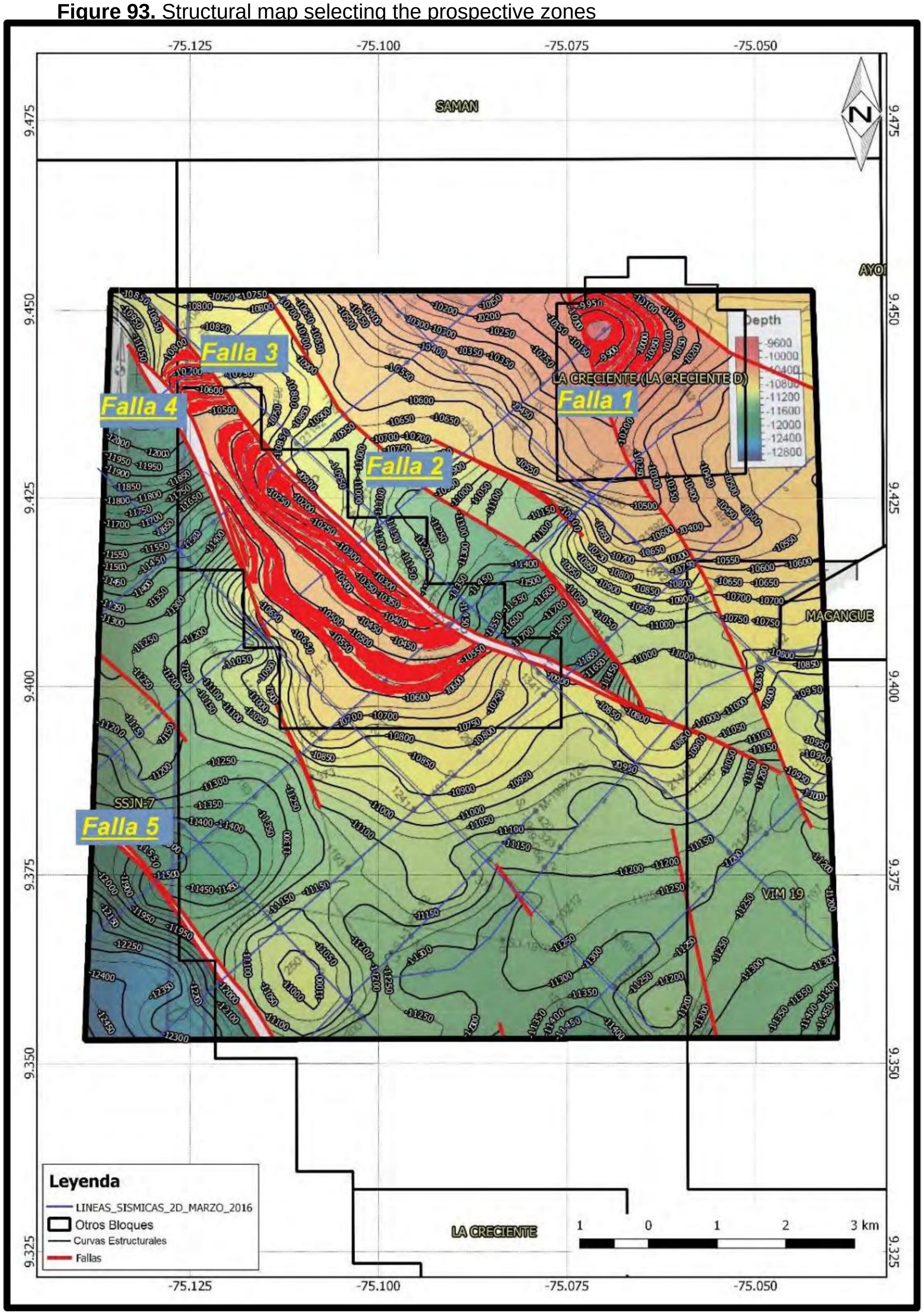


Source: Chapter 4, Virtual Structural Geology, W.Griem (1999-2015)

The contours that indicate the areas suitable for hydrocarbon accumulation are denoted in red based on the previous descriptions. On the map, two areas suitable for trapping can be identified, the first is the segment trapped between fault 4 and fault 3, the second is located in the flank that rose with respect to fault 1. As illustrated in **Figure 93.**

[29] Wolfgang Griem, Virtual Structural Geology, Published: 2005.

Figure 93. Structural map selecting the prospective zones

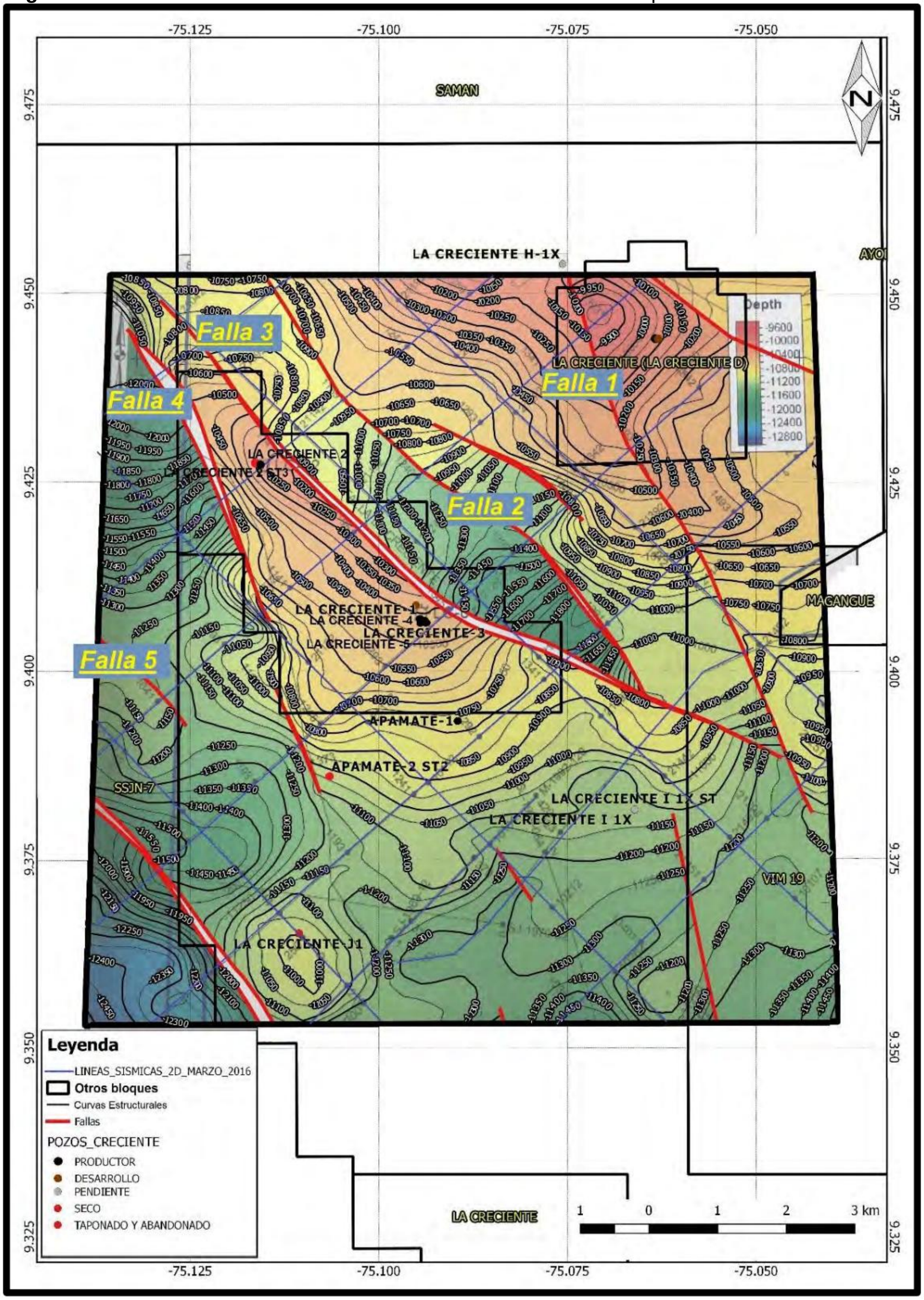


Source: analysis of Pacific Rubiales seismic results, modified by the authors.

With information taken from the National Hydrocarbons Agency (ANH), it was identified that the following wells were drilled: La Creciente 1, La Creciente 2, La Creciente 2 ST-3, La Creciente 3, La Creciente 4, La Creciente 5, Apamate 1, Apamete 1X, Apamate 2, Apamate 2 ST1, La Creciente H – 1X, La Creciente D1, La Creciente I – 1X and La Creciente J1. Which were located within the structural map as shown in Figure **94.**

The location of the wells allows us to delimit the areas where hydrocarbon accumulation exists and to validate previous analyses.

Figure 94. Location of wells in La Creciente Field on the structural map



Source: analysis of Pacific Rubiales seismic results, modified by the authors.

To conclude the analysis on the structural map at the top of the Ciénaga de Oro Formation, the location of the LCA-5 well was verified, where the top is located at 10,400 feet deep and in the master log it is located at 11,157 feet deep. The top of the Ciénaga de Oro Formation is also known for the LCA-3 well, where its top is located at 10,900 feet deep and in the structural map it is located at 10,450 feet deep.

It can be established that there are inconsistencies in the structural map at the top of the Ciénaga de Oro Formation since the depth of the LCA-3 and LCA-5 wells do not match, but it cannot be defined that the map is completely wrong because more information is needed to verify the map in its entirety.

5.2 CORRELATION OF OIL AND GAS SEARCH TECHNOLOGY (OFT) ANOMALIES WITH THE STRUCTURAL MAP

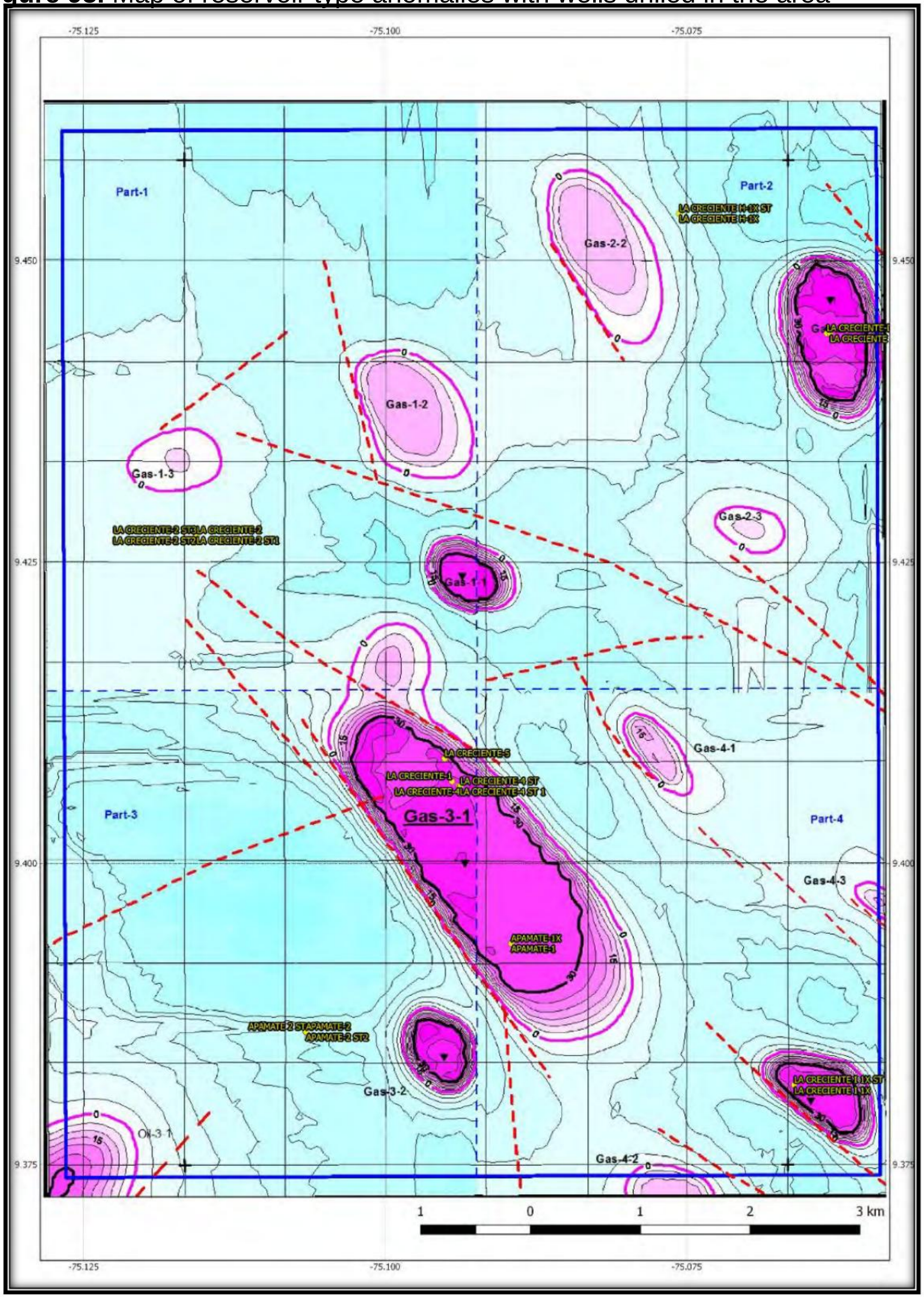
The following chapter presents the correlations made on the structural map, based on the superposition of the results of the oil and gas exploration technology (OFT).

5.2.1 Analysis. Based on the information obtained from the structural map at the top of the Ciénaga de Oro formation, an analysis was established that consisted of identifying the most favorable areas for hydrocarbon accumulation in the structural map, plus the wells drilled in this area, and then complementing it with the information obtained with oil and gas search technology (OFT), generating a better characterization in the La Creciente Block.

It is important to highlight that the geological and structural information on drilled wells is limited and the study was carried out with public information.

Figure **95** establishes the anomalies found in the La Creciente Block for Phase 1 satellite spectrography; the wells drilled in the block were located on this Figure.

Figure 95. Map of reservoir-type anomalies with wells drilled in the area



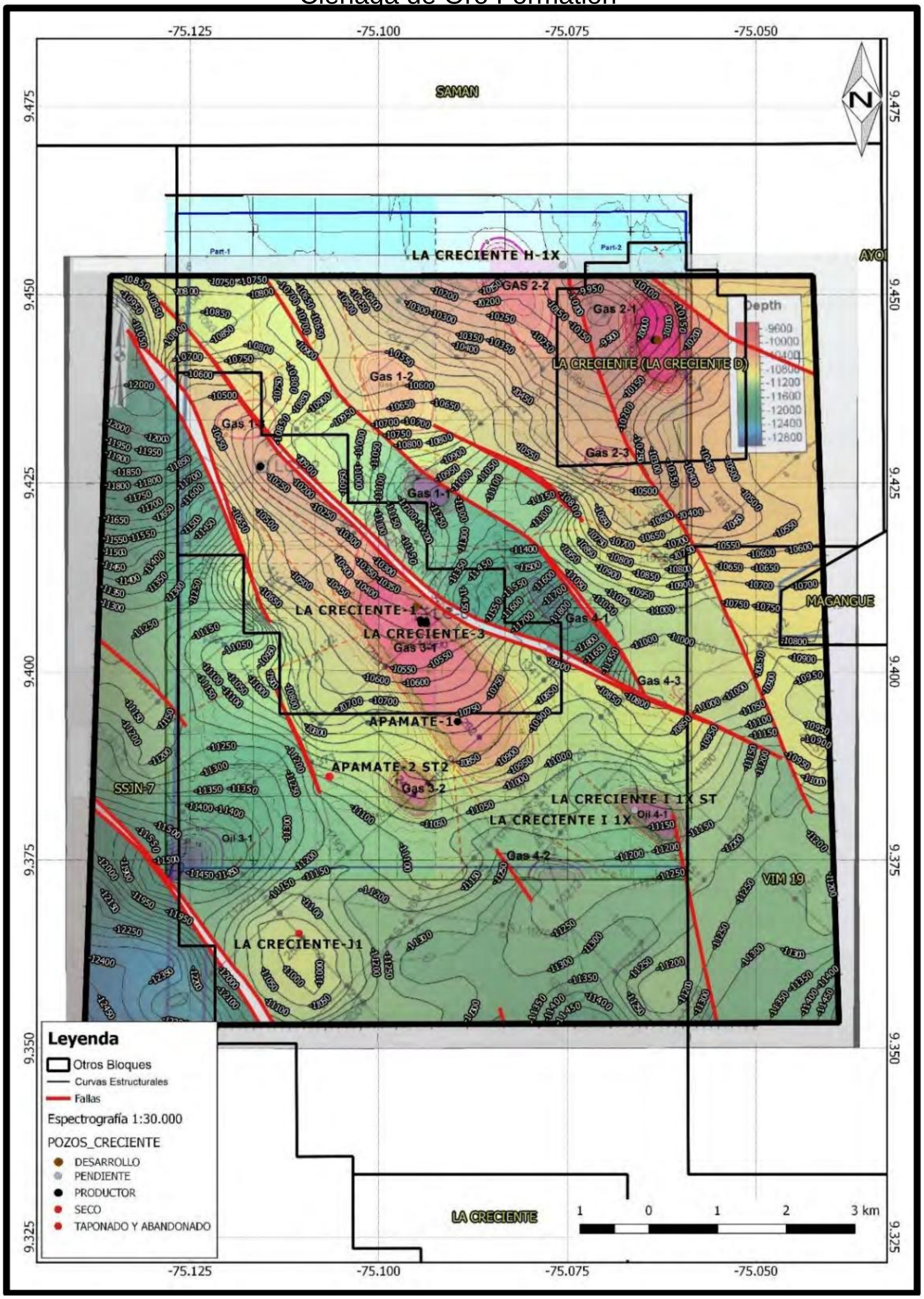
Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

For Phase 1 of the oil and gas exploration technology (OFT), the main anomaly was Gas 3-1, the wells that have been drilled are located inside the anomaly which can be considered a success story, but the opposite occurs when the anomalies of the Northern Zone are observed such as Gas 2-

1, Gas 2-2, Gas 1-2, Gas 1-3, in which the wells executed on these are not on the main area of the anomaly which leads to a great uncertainty of the exploratory success. The same occurs for the Oil 4-1 anomaly corresponding to the South Zone, the few wells are on the edge of this anomaly, however, it was explained in the previous chapter that Phase 2 ECECI and Phase 3 SVER show a more detailed area of the anomalies, hence the importance of executing the 3 phases of the oil and gas search technology (OFT) on an area.

After having delimited the location of the wells in **Figure 95,** the anomalies with the wells are placed on the structural map of the Ciénaga de Oro Formation as illustrated in **Figure 96,** to verify if they agree with the areas that the structural map indicates as favorable for the accumulation of hydrocarbons with respect to the information of the anomalies obtained by the oil and gas search technology (OFT) to generate the prospective hydrocarbon zones for future drilling plans.

Figure 96. Map of reservoir-type anomalies on a structural map in the Ciénaga de Oro Formation



Source: Analysis of Pacific Rubiales seismic results, CTAC Advanced Technologies Company, modified by the authors.

As seen in **Figure 96,** when comparing the anomalies it was identified that the majority tend to be located in the areas that were said to be favorable in the structural map, more exactly in the fault zone, as for the most important areas and with the greatest quantity of hydrocarbon corresponds to the Gas 3-1 anomaly (on this area the La Creciente Block began its exploration), but there are also other areas with interesting potentials that will be addressed later in the analysis carried out in Phase 2 ECECI and Phase 3 SVER, which within the polygon defined in the La Creciente Block correspond to the North zone Anomalies Gas 2-1, Gas 2-2, Gas 2-3, Gas 2-4, and the South zone with the Oil 4-1 anomaly.

The first validation that was identified on the La Creciente Block corresponds to the area where the Gas 3-1 anomaly is located, since within this anomaly are the wells La Creciente 1, La Creciente 3, La Creciente 4, La Creciente 5, Apamate – 1 and Apamate – 1X. These wells are producers and development wells that allow draining the proven reserves of the La Creciente Block, therefore, the oil and gas search technology (OFT) validates the presence of hydrocarbons on this area (structural high) and in addition the anomaly is coupled with the fault structure of the same (fault 3). These wells are located on the structural curves of 10,350, 10,450 and 10,750 feet, being in areas with structural closure.

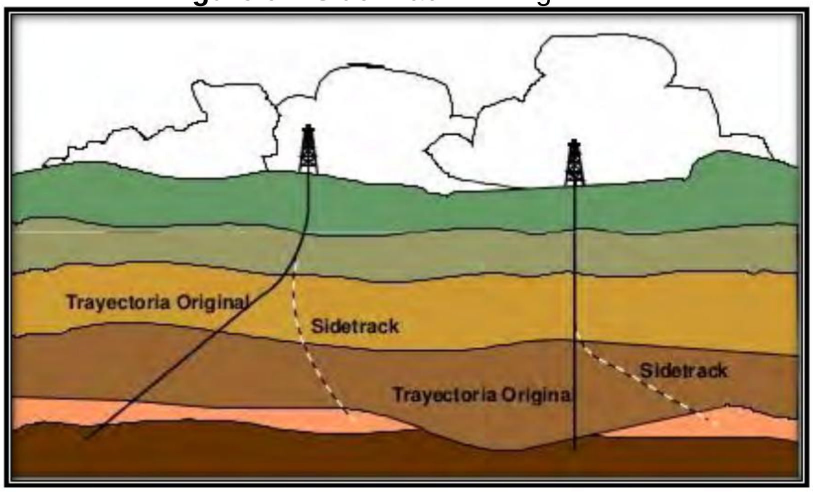
A similar case occurred for the wells La Creciente 2, La Creciente 2-ST1, La Creciente 2-ST2. These wells were drilled in the years 2007 to 2008 and as observed in **Figure 96,** these wells are over an area in which the oil and gas exploration technology (OFT) does not indicate the presence of hydrocarbons, and added to verify the validity of the information, these wells turned out to be dry, although the wells are over the structural curves of 10,300 and 10,350 feet, denoting the presence of hydrocarbons until the structural closure.

Continuing with the analysis, the behavior of these wells can be seen that there is the well La Creciente 2 - ST3, this well was not named previously since like the wells La Creciente 2 - ST1, La Creciente 2 -ST2 corresponds to the Side Track drilling. When Side Track is performed in a location, it is done in order to achieve better productivity in the reservoirs, this consists of deviated drilling, since it is designed to cross the geological zone interpreted as most favorable in the structure that houses the deposit as illustrated in **Figure 97,** in this case several side tracks were performed until the point where one of these was successful showing that the appropriate lithology was reached.

The Oil 3-1 anomaly was determined in Phase 1 of small-sized satellite spectrography, and was related to information from nearby drilled wells, leading to a hypothesis that this anomaly may not be correct in this area, since only water was found in the sector. This anomaly is located in an area not suitable for hydrocarbon accumulation because it is

It is located on a structural low, this anomaly is located near seismic lines ensuring that this area is studied and it could not be assured that it is an error in the structural map, therefore it generates uncertainty since an error is defined in the oil and gas search technology (OFT), presenting little precision in small anomalies demonstrating a limitation in its first phase, indicating that for a conclusive analysis the 3 phases must be run.

Figure 97. Side Track Drilling

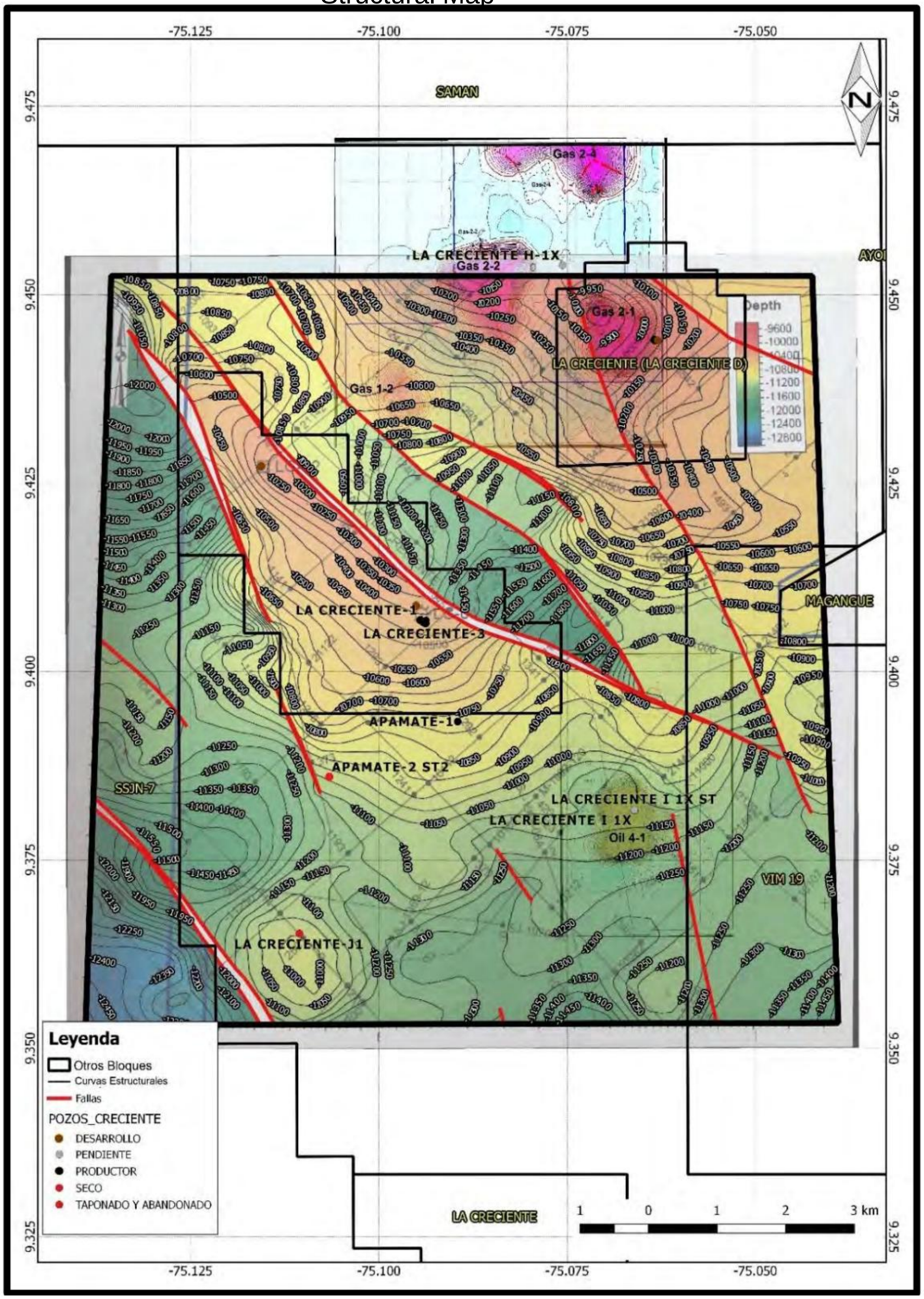


Source: Side Track Drilling, taken from the Basic Directional Drilling course by Eng. Mirco Guzman 9/2009.

It is important to mention that for Phase 2 ECECI and Phase 3 SVER, the operating company excluded the Gas 3-1 anomaly and its surroundings since this area is the one with the most information regarding the block, unlike the North and South Zones.

For **Figure 98,** the results obtained with the oil and gas exploration technology (OFT) were evaluated on the structural map of the Ciénaga de Oro Formation, but in this case the analysis is focused on Phase 2 ECECI and Phase 3 SVER. Within these phases, the difference with respect to Phase 1 will be the greater precision and accuracy of the shape of the anomalies since, in addition to satellite images, these works are carried out in the field, allowing the deposit to be delimited in a more adequate manner.

Figure 98. ECECI Phase 2 anomalies, location of La Creciente Block wells on Structural Map



Source: Analysis of Pacific Rubiales seismic results, CTAC Advanced Technologies Company, modified by the authors.

Based on the above analysis, it was identified that in the Northern Zone, the anomalies Gas 2-1, Gas 2-2, Gas 1-2 and Gas 2-4, the spectrum of the anomaly tends to change shape, coupling with the responses that were provided by the oil and gas search technology (OFT) team, as well as it is seen on which area of the entire anomaly concentrates the greatest electromagnetic pulse; For the wells that are located on the Gas 2-1 anomaly, it is observed that these wells (La Creciente D-1 and La Creciente D-2) border the anomaly on the right side, they are within but are not on the area of greatest interest, the opposite occurs with the Gas 2-2 anomaly in this anomaly with an important prospecting area, there is no well drilled and those that are supposed to be in this anomaly are located at a point where, according to the oil and gas search technology (OFT), it indicated the non-presence of hydrocarbons (wells La Creciente H-1X ST, La Creciente H-1X), these wells, according to the public information that exists, are being tested with a view to being abandoned. Regarding the Gas 1-2 anomaly, it is in a smaller area, but the Gas 2-4 anomaly, which was not identified in Phase 1 but was in Phase 2 ECECI, shows that within the area of the Block there is very good hydrocarbon prospecting and with a view to being explored with the drilling of wells. This can be seen as shown in **Figure 98.**

In turn, for the South Zone, the Oil 4-1 anomaly indicates the presence of gas condensate type fluid, and the drilled wells (La Creciente I 1X-ST, La Creciente I 1X) are located within the anomaly in an area with very good prospects for finding hydrocarbons **(Figure 98)** and because this information is confidential, the result of these wells is unknown and they have been the last drilling projects that the company has executed.

Once Phase 2 ECECI of the oil and gas search technology (OFT) has been evaluated, the average depths indicated by the structural map are established using the structural map and will be compared with the depths obtained in Phase 3 SVER of the oil and gas search technology (OFT).

This comparison is made for the anomalies Gas 2-1, Gas 2-2, Gas 1-2, Gas 2-4 and Oil 4-1, finding that in the North Zone they correspond to the anomalies Gas 2-1, Gas 2-2, Gas 1-2 and Gas 2-4, the depths established in the structural map for the Ciénaga de Oro Formation are between 10,000 and 10,600

feet and for the SVER Phase 3, the Ciénaga de Oro Formation is located between 10,000 – 10,400 feet.

The same occurs for the South Zone corresponding to the Oil 4-1 anomaly, in this anomaly it indicates that on the structural map the Ciénaga de Oro Formation is located between 11,000 and 11,200 feet, in the same way the depth established by Phase 3 SVER, the Ciénaga de Oro Formation is located at 11,000 -11,300 feet. As can be seen, there is a relationship between the data obtained in conventional methods with the new technologies, which immediately breaks the paradigms that have been established in the oil industry.

OFT technology is a complementary indicator to conventional study, but there is no valid precision in the entire study area since it is not very effective in georeferencing because the anomalies are over the area, but geologically an exact correlation between them was not evident.

5.3 MODIFIED STRUCTURAL MAP

The following map is made based on the contribution of the results of the oil and gas exploration technology (OFT).

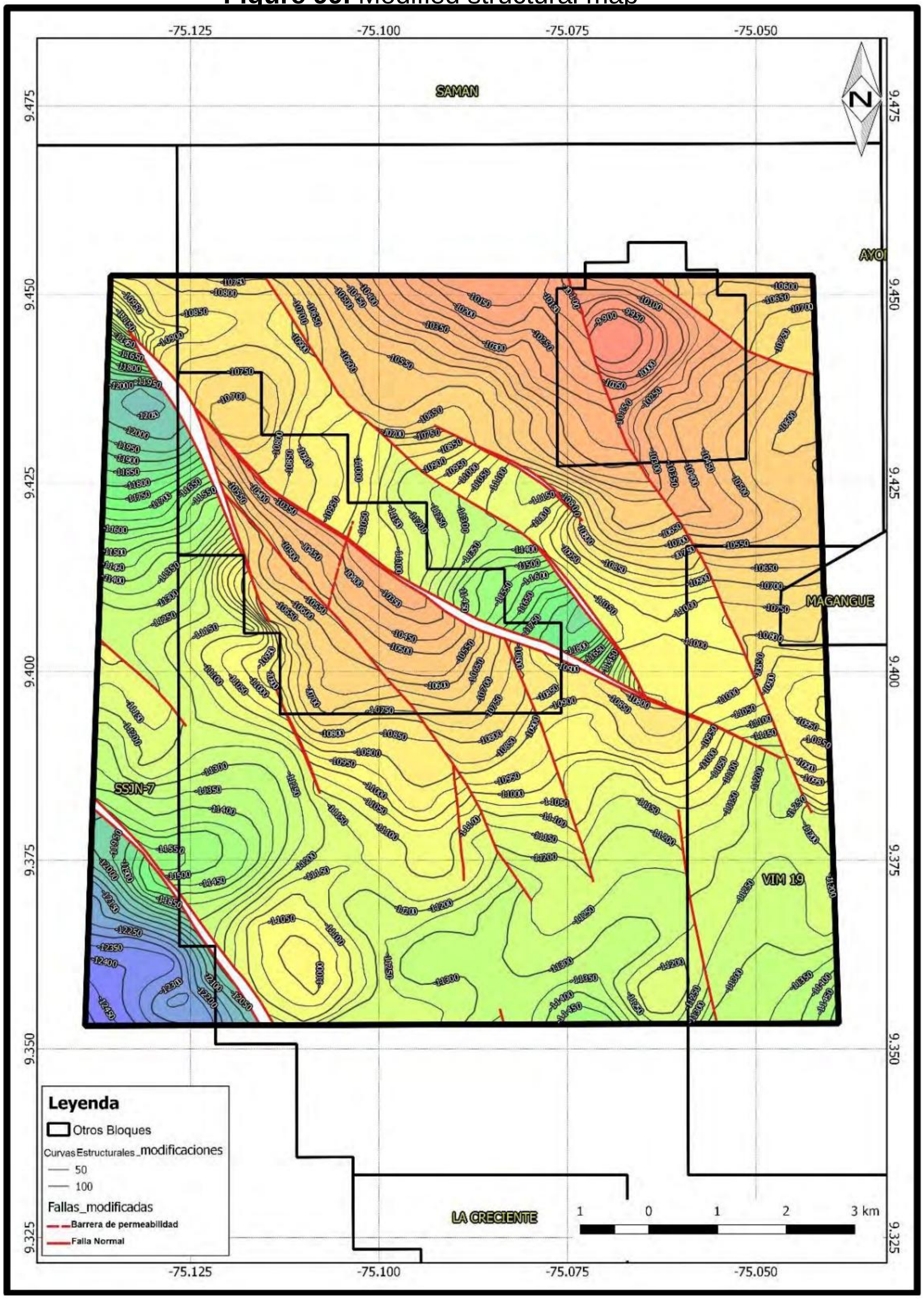
5.3.1 Map and analysis. In Figure 96, the location of the anomalies on the structural map at the top of the Ciénaga de Oro formation, a possible error in the preparation of this map by the company Pacific Rubiales could be seen, because the normal fault (fault 3) that crosses the Gas 3-1 anomaly, based on analysis of geological structures, would suppose the presence of hydrocarbons in the entire stratum towards the upper part, but in this area there are the wells La Creciente 2, La Creciente 2-ST1, La Creciente 2-ST2 and La Creciente 2- ST3, of which 3 were dry.

Due to the confidentiality of the information, the direction of these Side Tracks is not known, but as shown in Figure **96,** close to this area is the Gas 1-3 anomaly, which concludes that the La Creciente 2 – ST3 well could have been heading towards this area. The other major possibility that was determined for the creation of **Figure 99** is the hypothesis about the size of the Gas 3-1 anomaly, since it must be larger, increasing the presence of hydrocarbon in a North-West direction as occurs in the North and South zones, because the satellite spectrography, compared to phase 2 ECECI, only denotes the presence of hydrocarbon, but does not exactly delimit the size of the accumulation.

For this reason, the normal fault (fault 3) is moved, since the Spill Point, which is the lowest point in the structure where the fault can be trapped,
hydrocarbon, and once the trap has been filled to its spill point, its subsequent storage or retention of hydrocarbons will not occur due to lack of storage space within that trap but they continue to migrate until they are trapped elsewhere, this hypothesis suggests the behavior observed in the perforations carried out in that area corresponding to the wells La Creciente 2, La Creciente 2-ST1 and La Creciente 2-ST2 resulted in the wells drilled in this area being unsuccessful and only the well La Creciente 2-ST3 was a producer, in addition a permeability barrier is established delimiting the closure of the fluid in the structure of the Gas 3-1 anomaly for the closure of the structure in this part of the block.

The concept of this analysis was based on the results obtained in the 4 existing wells, finding a producing horizon in another unestablished area and according to the structural map, it indicated that there should be hydrocarbon presence over this area. What the assessment indicates does not correspond to what was established, which is why, as the structural map is also an analysis made by a specialized interpreter, but not exempt from human errors, for the final map the fault (fault 3) was changed and moved to create a new interpretation based on the analysis made by the authors.

Figure 99. Modified structural map



Source: Analysis of Pacific Rubiales seismic results, CTAC Advanced Technologies Company, modified by the authors.

Regarding the North and South zones, only adjustments were made to the contour lines based on the anomalies to better detail the area of hydrocarbon presence, in order to then be able to locate the water-gas and gas-oil contacts with respect to the OFT information vs. the results of the drilled wells.

Neither of the two processes is absolute, this is why the structural map was adjusted to the anomalies found as illustrated in **Figure 100,** but the complementarity is still important, as is the case of the seismic study when a body has a dip and the waves generated take a different route to the return, as well as when the calculation is carried out that point is not exact and has a variation, the same occurs when the data is migrated since the speeds are not exact either and are based on the interpretations of specialized people. As is the case of the location of the LCA-3 and LCA-5 wells that did not coincide with the top of the Ciénaga de Oro Formation with respect to the perforations of these wells with the structural map, therefore, the structural map is not absolute as well as the technology for searching for oil and gas (OFT) is not absolute. Because the first phase of the technology evaluated is observed from a satellite and indicates the existence of the hydrocarbon, but only the existence.

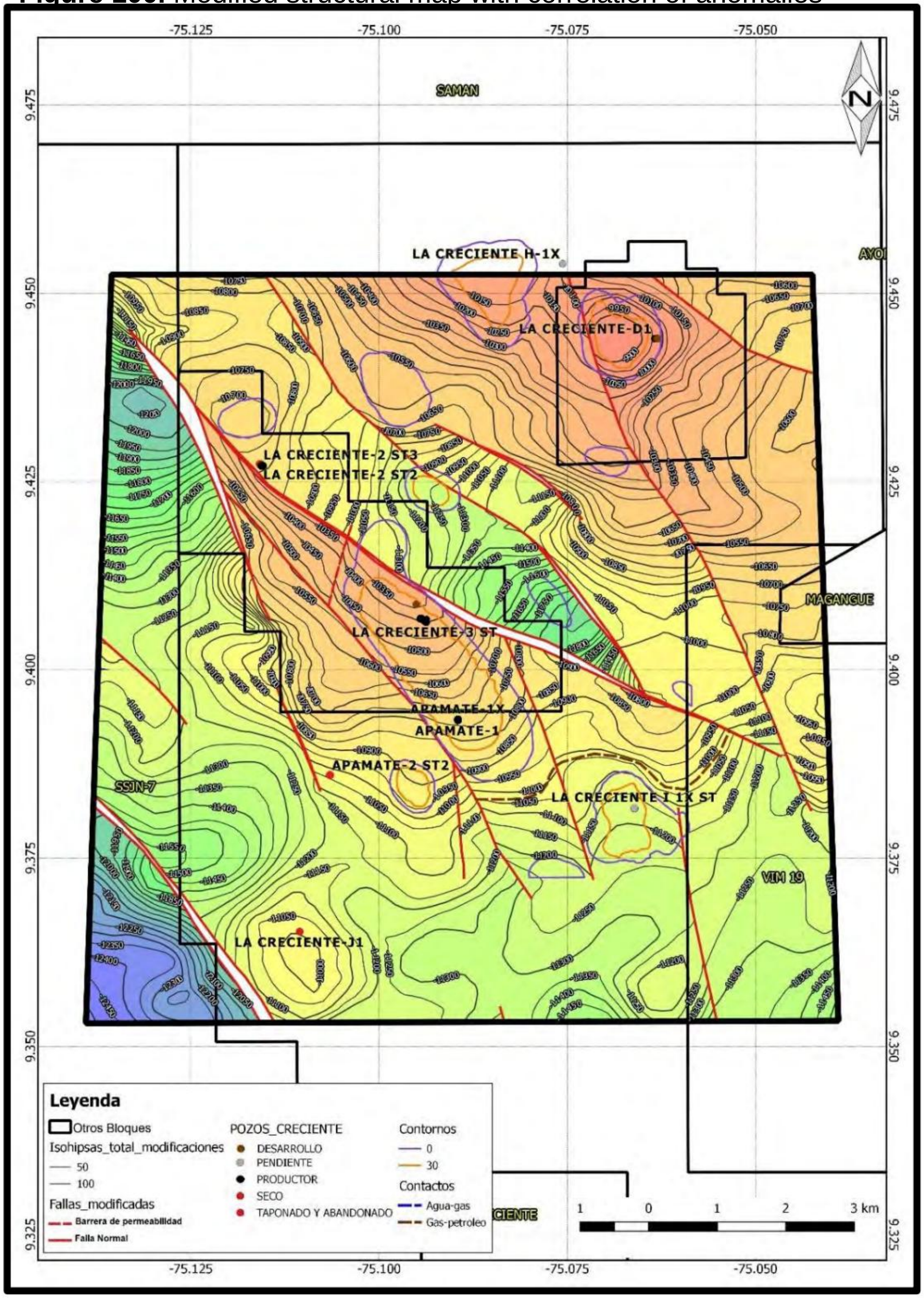
Figure **100** shows the modified map by adding the OFT technology contours, where the purple contour indicates the start of the anomaly and the orange contour represents the greatest presence of hydrocarbon.

By making the final adjustment, it was possible to determine the complement of the OFT technology on the study area where the presence of hydrocarbon is evident, as previously observed in the superposition of the anomalies on the structural map, the location of the wells coincide with respect to the anomalous zones, but the contour lines did not adjust to certain anomalies as well as the anomalies to the structural map.

The combination of information from both technologies made it possible to delimit the areas through oil-gas contact, located in order to relate the areas where drilling a well would not be recommended.

OFT technology is an excellent complement to conventional registers, allowing you to select where these registers should be run, saving costs and work time.

Figure 100. Modified structural map with correlation of anomalies



Source: Analysis of Pacific Rubiales seismic results, CTAC Advanced Technologies Company, modified by the authors.

5.4 COMPARISON OF STUDY TOOLS

This chapter compares conventional technologies with oil and gas exploration technology (OFT) as illustrated in **Table 15,** in order to evaluate their performance and conclude which is more optimal for an exploration process.

Table 15. Comparative table evaluating the efficiency of analysis aspects of conventional logs versus oil and gas exploration technology (OFT)

Parameter a compare	**Seismic record Electrical**	**records**	**(OFT) Technology**
Factors that affect your reading	Interferences	Type of minerals and fluids in the formation	None
Depth range of studies	0-50,000 feet	It depends on the drilling depth and inclination.	0-98,000 feet
Time to perform measurement	From 1 to 3 weeks depending on the number of kilometers. area and after having obtained the exploration license (1 to 3 months)	From 1 to 2 weeks after the well has been drilled (from 1 to 3 months after obtaining the drilling license and an additional 1 to 3 weeks drilling the well and will depend on the number of wells in the area	From 15 to 25 days in all its 3 phases
Danger in execution	Poor application of the burst for wave induction can cause fractures in the subsoil	Lost registry tool	None

Table 15. (Continued)

Parameter a compare	**Seismic record**	**Electrical records**	**(OFT) Technology**
Access to the area of study	It will depend on the routes of access for your arrival to be able to carry the tools	It will depend on the routes of access for your arrival to be able to carry the tools	In the first phase there is no limitation, but in the other two phases it will depend on the access routes for your arrival.
That does not identify	Fluids (hydrocarbon, water)	To achieve a characterization it is necessary to run a set of records	Rock properties (porosity, permeability)

Based on the previous comparison, a comparative table is made that delimits what each technology obtains by adding an additional factor, which is the information obtained from a well as shown in **Table 16.**

Table 16. Reservoir Characterization

Reservoir Characterization					
Oil and Gas Search Technology (OFT)			Seismic record	Electrical records	With a well
Phase 1 Spectrography to	Phase 2 ECECI	Phase 3 SVER	Tectonic style Structural geology Lithology Traps Position in depth Volume calculation	Lithology Identify fluid intake Fractures	True depth Type of hydrocarbon Lithology Calculations of Reservations
Evidence of hydrocarbons in the area Type of fluids	Shape delimits-tion of deposit orFaults	Depth and thicknesses			

6. FINANCIAL CHAPTER

In the next chapter you will find the financial analysis made for the oil and gas exploration technology (OFT), comparing the costs in the CAPEX (capital costs) and OPEX (operating costs) analysis of both this technology and the conventional exploration method.

The financial evaluation carried out is represented in the associated costs generated with respect to the use of oil and gas search technology (OFT), over an area of 89 km2 located on the Lower Magdalena Valley Basin, department of Sucre, municipality of San Pedro, in order to identify the presence of anomalous zones regarding the presence of hydrocarbon-type fluids in the La Creciente Field.

For this purpose, an assessment of the impact in financial terms is carried out, aimed at studying the La Creciente Field through the use of oil and gas search technology (OFT), in relation to the costs generated by the services provided by this technology, which in this case are contracted by the operator in contrast to the costs generated by conventional technologies.

6.1 THEORETICAL ANALYSIS OF THE IMPACT IN FINANCIAL TERMS

The economic impact analysis for the project focuses on performing the corresponding calculations using the cost indicator (CAPEX and OPEX) to quantify the benefits provided by the oil and gas search technology (OFT) as well as allowing the client to make the decision because by generating a low CAPEX value, the client's financial capacity will allow them to focus the investment in prospective areas that can generate capital investment reflected in lower operating costs, as opposed to having a large volume of CAPEX that would not generate an expected profit margin due to higher operating costs.

For this reason, the investment cost of this service is focused on the acquisition of the asset with the benefit of generating in the investor the security of making a decision so that future projects that are going to be carried out are carried out with successful results or, on the contrary, they decide not to invest more money so as not to generate capital losses.

The idea of an analysis using these indicators is to be able to convert low CAPEX to low OPEX in order to have a higher percentage of profits and profitability.

It is vitally important to clarify that the data with which the financial calculations were made were data provided by the company, based on the work carried out in the La Creciente Field and added to other work carried out at the level national and international, in order to obtain the cost of using oil and gas exploration technology (OFT).

6.1.1 Capex. This is the abbreviation of the English expression Capital Expenditure and is the amount of money spent on the acquisition (or improvement) of the capital assets of a particular company. CAPEX is therefore the amount of investment in equipment and facilities in order to maintain the production of a product or service or to keep a particular business or system running.

6.1.2 Opex. Refers to the costs associated with equipment maintenance and consumables and other operating expenses necessary for the production and operation of the business or system. For example, the purchase of a machine is CAPEX, while the maintenance cost is OPEX.

6.1.3 Revenues. These are the cash flows related to the provision of oil and gas search technology (OFT) services.

Project revenues were calculated based on US dollars, since the technology's core services are priced in dollars.

6.1.4 Costs. For the proposed project, the costs are reflected in the amount of money that is necessary for the execution of the stages, within these are specialized personnel, taxes, among others.

6.5.4.1 Variable costs. Variable costs refer to the proportion based on the number of kilometers or area that is covered by the technology in the development of its different phases. However, this cost will vary according to the investment margin made by the client company since it directly depends on the profitability they have.

The following are the variable costs in oil and gas exploration technology (OFT):

- Spectrography Work:

Equation 4. Cost Spectrography

$$Costo\ Espectrografía = 100\%\ de\ los\ Km^2\ de\ estudio * costo\ Km^2\ de\ la\ espectrografia$$

Source: CTAC – Advanced Technologies Company of Colombia SAS

Where the cost of spectrography is USD 4,750 per km2 .

- Field work corresponding to the second and third phase:

Equation 5. Field work cost

$$\text{Costo Trabajo en campo} = \text{area efectiva en } Km^2 * \text{costo } Km^2 \text{del trabajo en campo}$$

Source: CTAC – Advanced Technologies Company of Colombia SAS

Where the cost of field work is USD 18,700 per km2 .

6.5.4.2 Fixed costs. On the other hand, fixed costs are those that remain constant, and it will always be necessary to keep them active. These costs allow the company to remain active regardless of the amount of work it has at a given time. These expenses must be paid by the company, such as:

- Depreciation
- Insurance
- Public services
- Taxes
- Administrative area

In this case, the fixed cost has a value of 13,400 USD per month, which corresponds to payroll, office rent, utility payments and taxes, as mentioned in the previous example.

Logistics costs are also taken into account as a fixed cost because it is a value that does not depend on any variable and will always have the same value, which is equivalent to USD 10,000.

6.5.4.3 Total costs. Total costs are the sum of fixed costs and variable costs less the discount, which is calculated as agreed, since it will vary depending on the number of effective km2 of the study.

Equation 6. Total costs

$$\text{Costos Totales} = \text{trabajo espectrografia} + \text{trabajo en campo} + \text{costos de logistica} - \text{descuento}$$

Source: CTAC – Advanced Technologies Company of Colombia SAS

6.1.5 Preparation of cost tables. It should be noted that the company divides the execution of the oil and gas search technology into two services, therefore, a charge is made for the spectrography work and another charge for the field work, due to the fact that different tax and obligation payments are made.

Seismic Records and Electrical Records Tables

Table 1. Costs of seismic recordings

Length	**89**	km2
Seismic cost	**$ 14,500 1 km2*USD**	
Total cost	**$ 1,290,500 USD**	

Table 2. Electrical registration costs

Depth	**5,000 Ft**
Cost of records	**$ 30,000 1000Ft*USD**
Total cost	**$ 150,000 USD**

For a subtotal cost of $1,444,500 USD, the cost of an environmental license must be added to this value, which has an approximate value of $600,000 USD, which consists of the environmental license, the environmental impact study and the environmental management plan; giving a total of $2,044,500 USD.

Oil and Gas Technology (OFT) Tables

Table 3. Spectrography costs

Area	**89**	km2
Cost of spectrography	**$ 4,750 1 km2*USD**	
cost area	**$ 422,750 USD**	
Logistics	**$ 5,000 USD**	
Administrative cost	**$ 13,400 USD**	
Total cost	**$ 441,150 USD**	

Table 4. Field work costs

Effective area	**18**	km2
Field cost	**$ 18,700 1 km2*USD**	
Discount 3 km2 **-$ 56,100 USD**		
Logistics area	**$ 336,600 USD**	
cost $ 5,000 USD		
Administrative	**$ 13,400 USD**	
cost Total cost	**$ 317,618 USD**	

For a total cost of $758,768 USD

6.1.5.1 Cost comparison. Based on the calculations corresponding to conventional technologies (Table 1. Seismic Recording Costs and Table 2. Electrical Recording Costs) and the calculations corresponding to oil and gas search technology (OFT) (Table 3.
Costs Spectrography and Table 4. Field work costs), it was established that there is a difference between the costs of using conventional methods versus using oil and gas search technology (OFT), since the cost differential is $1,285,732 USD (2,044,500 USD-758,768 USD), taking into account the observation that oil and gas search technology (OFT) does not take into account the cost of the environmental license because it does not need it to carry out its work.

Conventional technologies took approximately 8 to 9 months to execute because they had to wait for the environmental license to be issued, then add the time to carry out seismic and geological studies to conclude whether it was possible to drill an exploratory well and compare it with the taking of electrical records, unlike the execution of oil and gas search technology (OFT) since from the time of planning to the completion of the three phases the total estimated time was 2 months, therefore the time difference is directly reflected in the cost of money factor over time.

6.1.6 Why invest in oil and gas exploration technology (OFT).

• It is a low-cost technology, since it can do its job in a short time.
time which implies cost reduction.
• It is a practical technology because it does not need many components to carry out its application, for example, to work in marine waters it does not require specialized vessels, measurements can be made in the air from any aircraft. • Its first phase allows its work to be carried out
from any remote location in the
world.
• It does not require licenses and permits, which allows the study to be carried out as soon as
possible. • Its high efficiency allows for increased success in drilling campaigns. • It is endorsed by the ANH as part of the contractual commitments

Table **17** compares conventional records (which consist of electrical records and seismic records) with respect to oil and gas search technology (OFT), evaluating each fundamental aspect that allows evaluating their performance.

Table 17. Comparison table of conventional logging versus oil and gas exploration technology (OFT)

Aspect to compare	**Conventional records**	**Oil and Gas Search Technology (OFT)**
Access	If you cannot reach the area of interest carrying all the tools, this would be a limitation in the application.	Since its first phase is carried out through the use of satellite, it can reach any location having the proper coordinates of the site of interest.
Costs	Average cost per effective square kilometer of $45,000 USD+VAT for 4D seismic and average cost of basic electrical records (Gamma Ray, Resistivity and SP) of $30,000 USD+VAT per 1000 feet.	Average cost per effective square kilometer of $23,450 USD + VAT
Efficiency	Between 20 to 40%	Between 60 to 80%
Permissions	Requires environmental licenses and permits because drilling is needed, detonations are carried out, which can generate change in the environment	It does not require environmental licenses or permits since its application does not need any drilling or detonation.
Staff	Minimum 14 people in application and evaluation of each registration	Maximum 10 people per phase
Time	An intermediate period between 10 to 20 days for each registration to reach the total distance required and 2 weeks for the processing of each registration.	A maximum period of 10 to 20 days for its three phases and 1 month for processing the information.

It is advisable to carry out the project because there are elements that allow cost savings, with the main one being the cost of the environmental license.

7. CONCLUSIONS

- Oil and gas exploration technology (OFT) was adjusted to previous analyses carried out in the area and allowed for the geological reinterpretation of the La Creciente Block in the Lower Magdalena Valley Basin.
- The joint analysis of conventional methods and OFT technology was able to interpret the geological distribution present in the area resembling the identified structures, and managing to update characterization maps on the Block under study.
- When performing the OFT analysis with the Master Log record, the top and base ranges identified by the geological analyses coincide.
- Using OFT technology, the areas in which exploratory projects resulted in dry and abandoned wells were identified, since the technology did not record the presence of hydrocarbons in these areas. In addition, based on the new interpretation, the location of the faults was determined in relation to the results of the drilled wells and the interpretation of the anomalies.
- The evaluated technology identified three new gas-containing zones for the possible location of exploratory wells, which are Gas 1-1, Gas 3-2 and Gas 2-2.
- For a conclusive OFT work, spectrography shows that there is hydrocarbon in the subsoil, but the shape, size, position and possible geometry of the deposit are only obtained with Phase 2 ECECI and Phase 3 SVER, which makes it necessary to carry out all 3 phases of the same.
- Seismic costs can be reduced by using OFT technology, as it allows for discriminating prospective from non-prospective areas.
- The results of the financial evaluation of the project indicate that it is economically profitable, since it allows a saving of 63%, which in monetary terms represents a saving of $1,285,732 USD compared to conventional technologies.

8. RECOMMENDATIONS

- Review the lithological information obtained in the wells La Creciente 2, La Creciente 2-ST1, La Creciente 2-ST2 and La Creciente 2- ST3 that allows a conclusive analysis in the anomalous zones Gas 3-1 and Gas 1-3.
- Conduct a 3D seismic study on each anomaly to make the corresponding reserve volume calculation as a complement to studies of oil and gas exploration technology (OFT) and for the correlation of subsurface geology.

- It is recommended to carry out seismic studies and evaluate the possibility of drilling Gas 1-1, Gas 3-2 and Gas 2-2 zones.

LITERATURE

Barrero Dario, Martinez Juan F, Pardo Andres, Vargas Carlos. Colombian Sedimentary Basins. National Hydrocarbons Agency, Bogota. 2007.

Geology Bulletin Vol. 26, No. 42, January-June 2004.

CTAC COLOMBIA. OFT [online]<http://www.ctac.com.co/oild-and-gas-finder-technology/ >[cited September 10, 2015].

Nonclassical Geophysics: Theses of International Conference. (Saratov, 28 Aug. – 1 Sept. 2000). – Saratov: IOFZ in the name of O Schmidt, AN FR, Nizhnevolskiy NNI of Geology and Geophysics. Saratov. Department of Eurasian Geophysical Training, 2000. – 79 pp.

Herrera Yajaira, Cooper Norman, 2010. Manual for the acquisition and processing of terrestrial seismic and its application in Colombia, Montes L. Alfredo, National University of Colombia.

Ingeominas, Contract 017-1994: Surface Geology of the Sinú San Jacinto Area. 1994.

COLOMBIAN INSTITUTE OF TECHNICAL STANDARDS. Colombian standards for the presentation of theses, degree projects and other research works. NTC 1486. Bogotá DC: The Institute, 2008. 110 p.

_________ . Bibliographic references, content, form and structure. NTC 5613. Bogotá DC: The Institute, 2008. 38 p.

_________ . Documentary references for electronic information sources. NTC 4490. Bogotá DC: The Institute, 2008. 30 p.

JotaErre.Net. [online] < https://jotaerre.net/2013/10/17/concepto-de-capex-opex/>[cited on October 17, 2013].

Kennett, Brian, 2009. Seismic Wave Propagation in Stratified Media, ANU E PRESS, The Australian National University, 1 - 6, 59 – 77.

Kurniawan Alva, Mc Kenzie Jhon, Putri Anita Jasmine, 2009. First Edition, General Dictionary of Geology. Environmental Geographic Student Association (EGSA).

Levashov SP, Yakimchuk MA, Korchaguin IM, Pishchanyi IM Electro-resonance sounding method and its capabilities in carrying out complex geological-geophysical studies.// Geoinformatics – 2003 – No 1 – Pages 15 – 20.

Levashov SP, Yakimchuk NA, Korchaguin IN, Taskinbaev KM Search and exploration of HC accumulations with geoelectrical methods in oil fields of Western Kazakhstan // Georesources – 2003 – No 1 – Pages 31 – 37.

Petroblogger. [online] http://www.ingenieriadepetroleo.com/registros-eléctricas-sp-gr-ngs.html [cited on February 10, 2013]

Petróleo América. [online] <http://www.petroleoamerica.com/2011/02/bienvenidos_5773.html> [cited on September 3, 2009].

Pirson SJ Prediction of hydrocarbons in place by magnetoelectrotelluric exploration// Oil and gas. J. – 1976 – 74, No 22 – Page 82 – 86.

Shuman VN Methods and models of electromagnetic sounding systems: status, limits and new capabilities // there. – 2006. – 28, No 1 – pp. 17 – 30.

Shuman VN Transient electromagnetic processes in a long time interval: physical-mathematical models and characteristics// Geof. Journal. – 2001. – 23, No 1. – p. 3 – 21.

Shuman VN on theoretical foundations of modern geoelectrics// there. – 2005. – 27, No 2. – Page 218 – 234.

Shuman VN, Prichepiy TI Optimum regimes of electromagnetic sounding systems with controlled field excitation in isotropic media with dispersion// Geophysical Journal – 2004 – 26, No 4 – Pages 55 – 62.

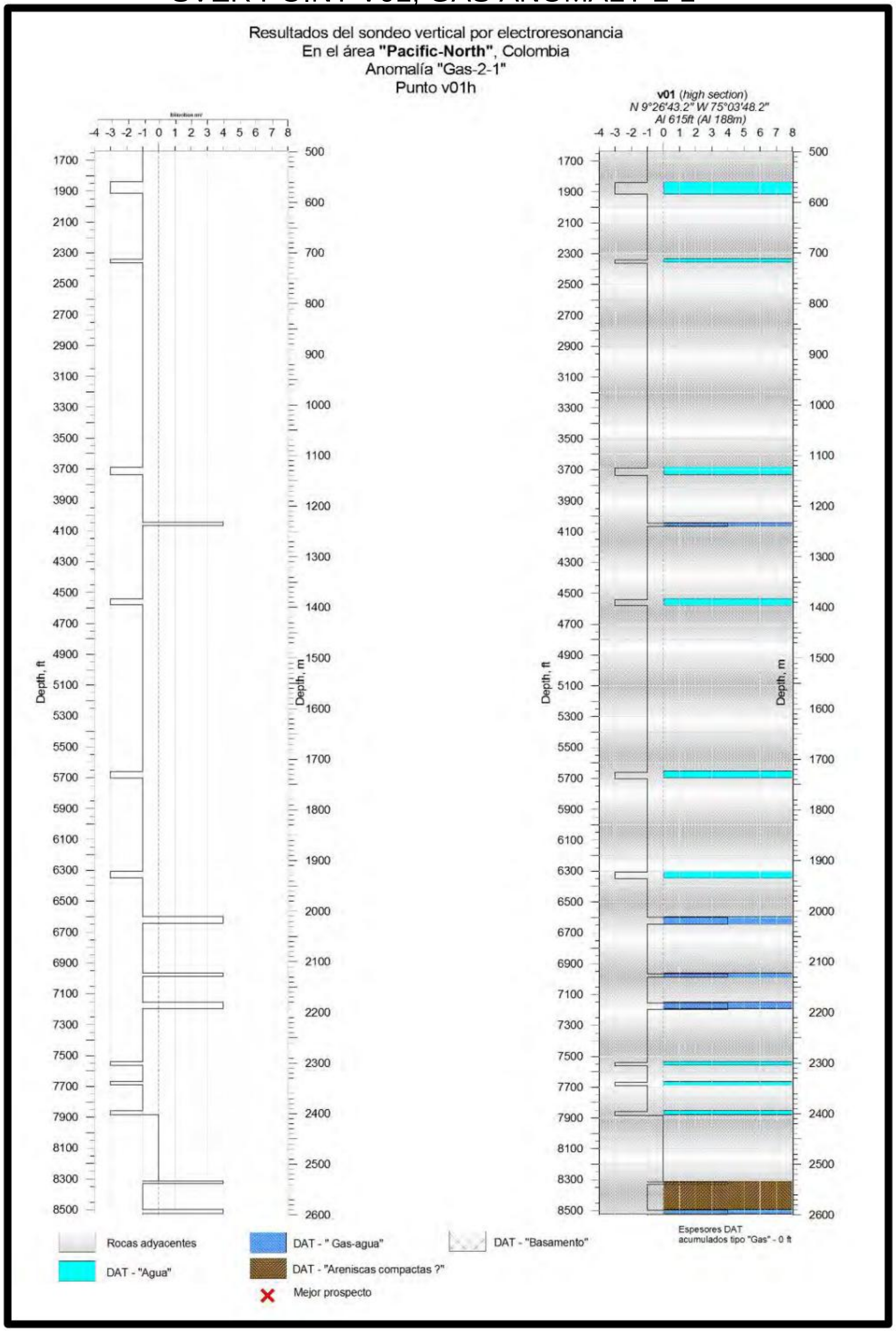
Schulmberger. Principles and applications of record interpretation. 2010.

Mining and Energy Planning Unit (UPME), Natural Gas Balance 2014-2023. 2014.

ANNEXES

ANNEX A

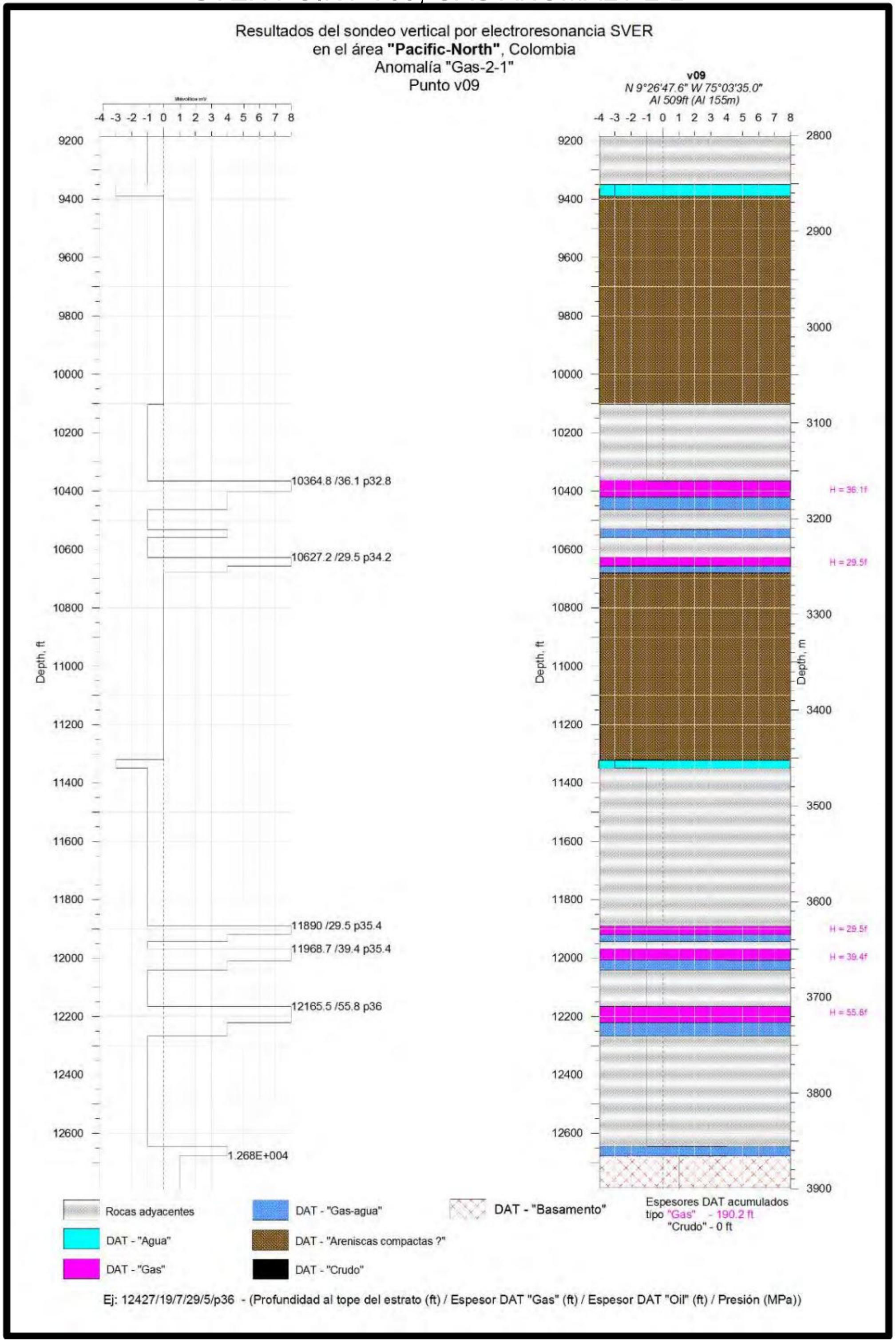
SVER POINT V01, GAS ANOMALY 2-1



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

ANNEX B

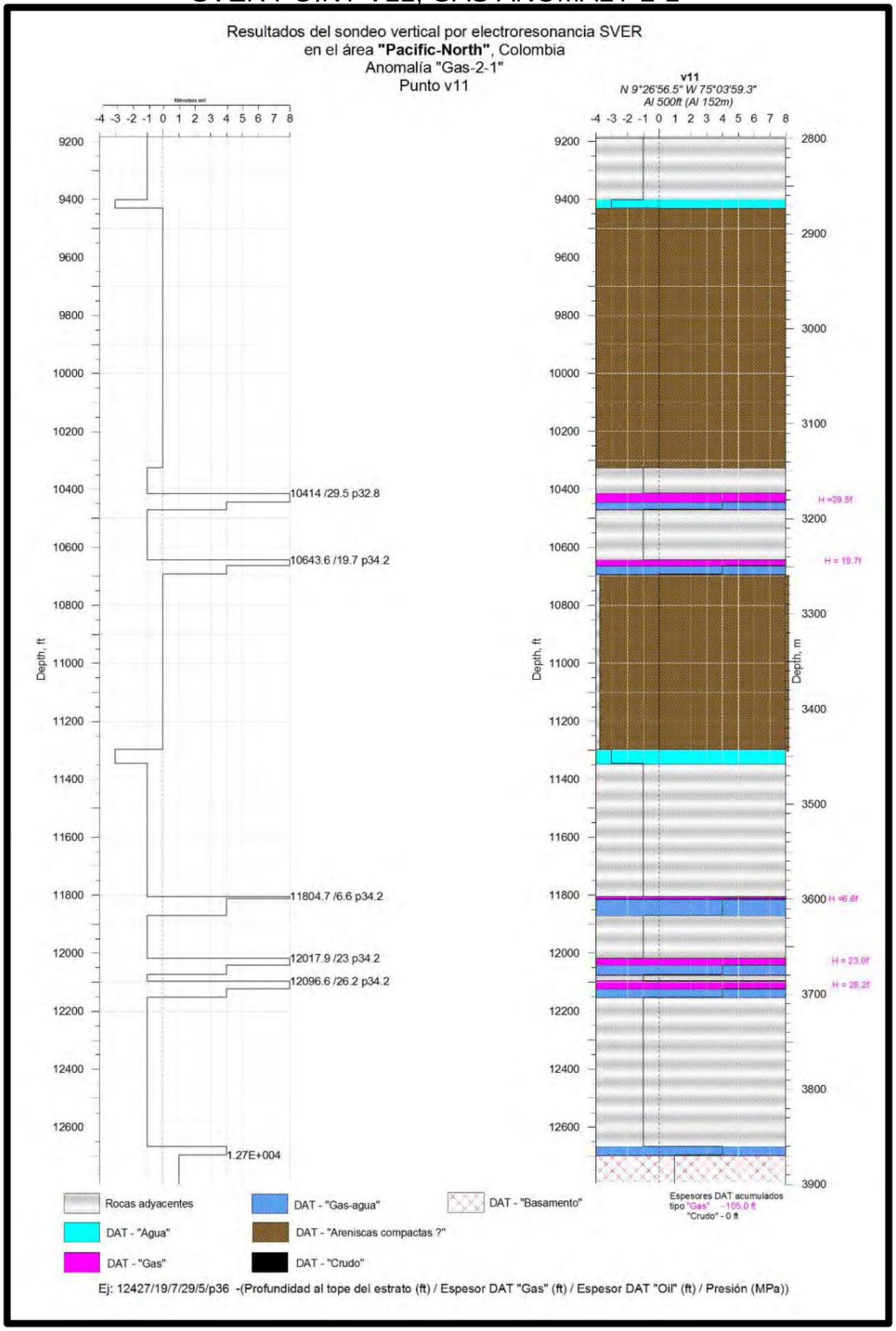
SVER POINT V09, GAS ANOMALY 2-1



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

ANNEX C

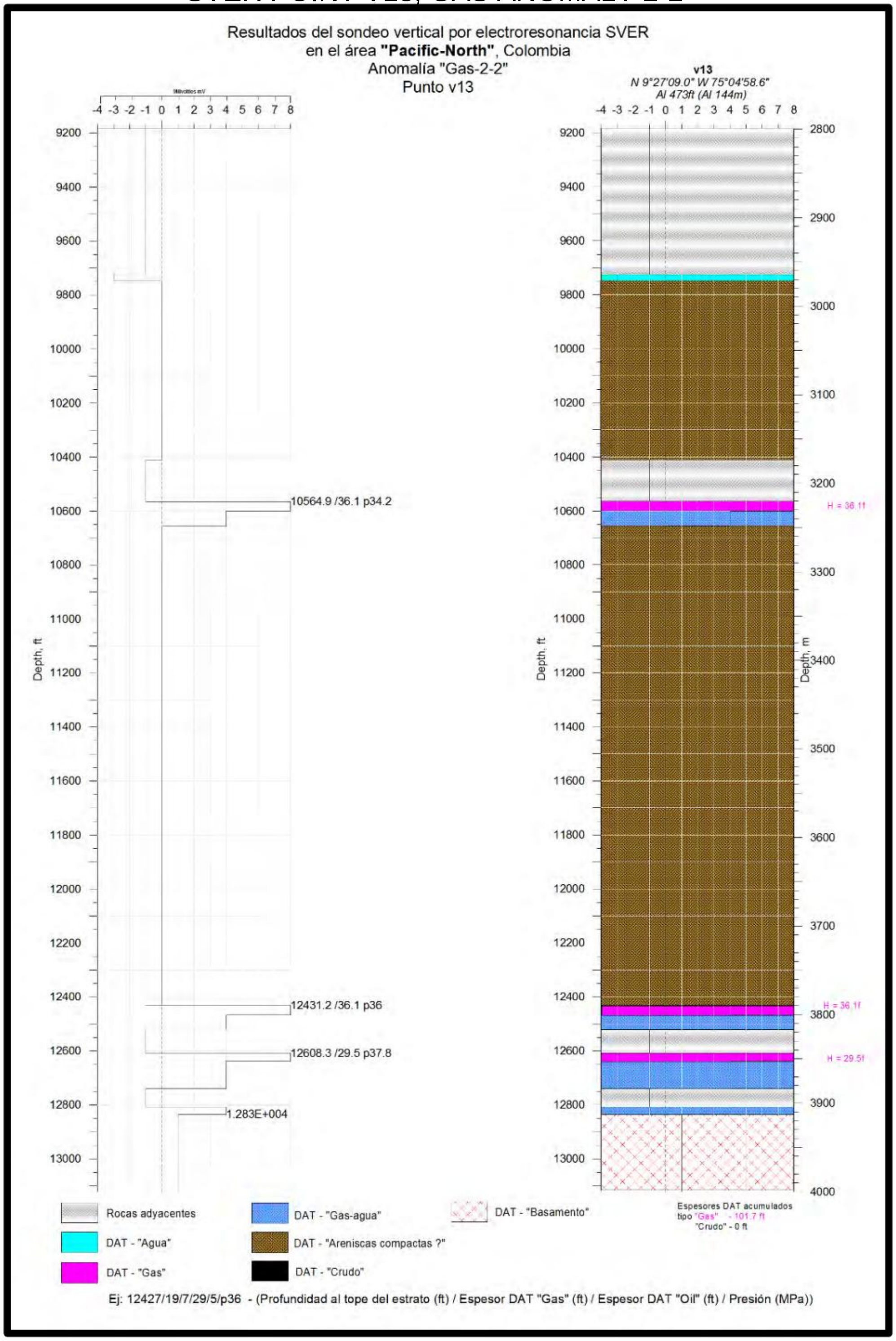
SVER POINT V11, GAS ANOMALY 2-1



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

ANNEX D

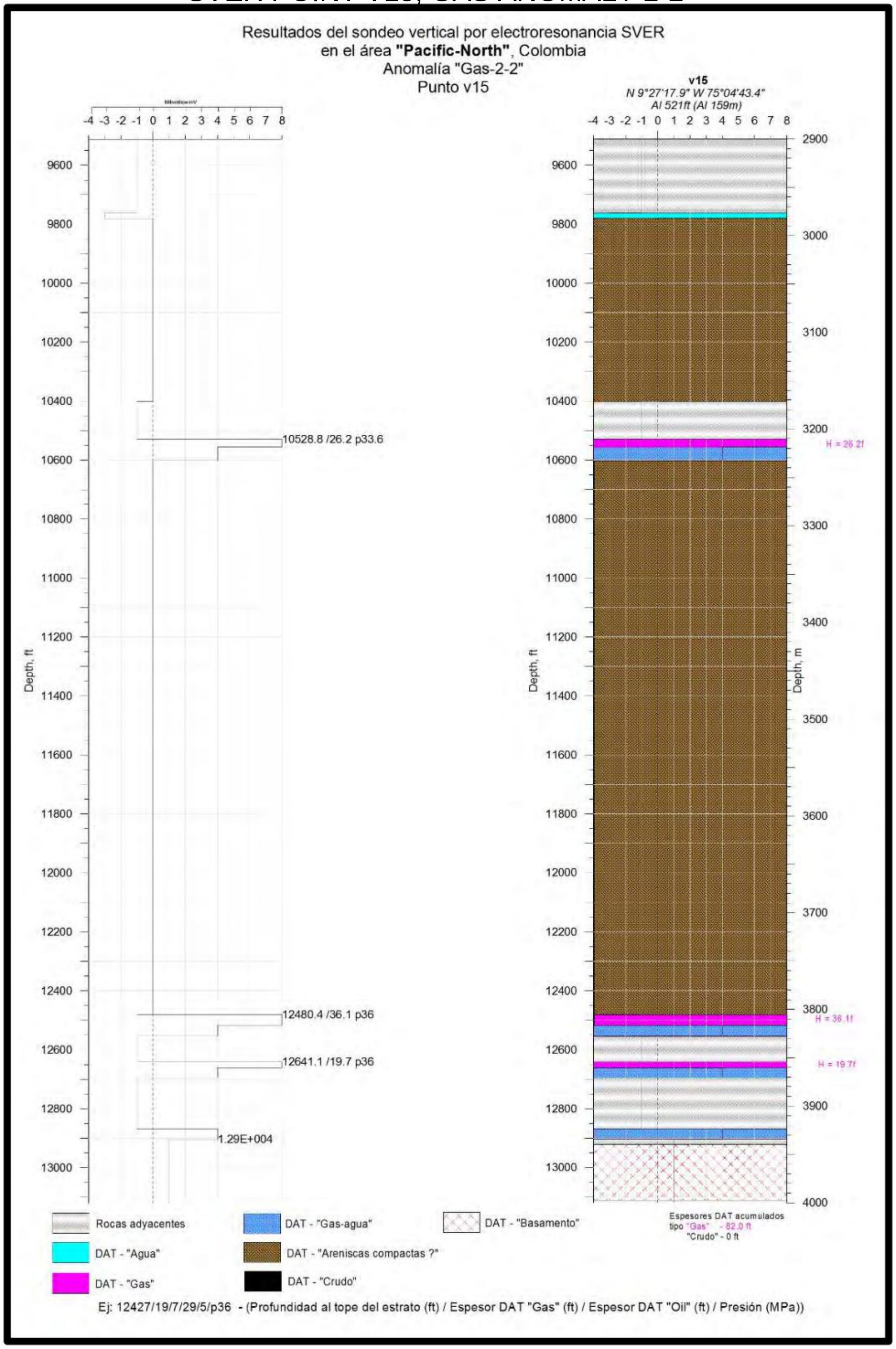
SVER POINT V13, GAS ANOMALY 2-2



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

ANNEX E

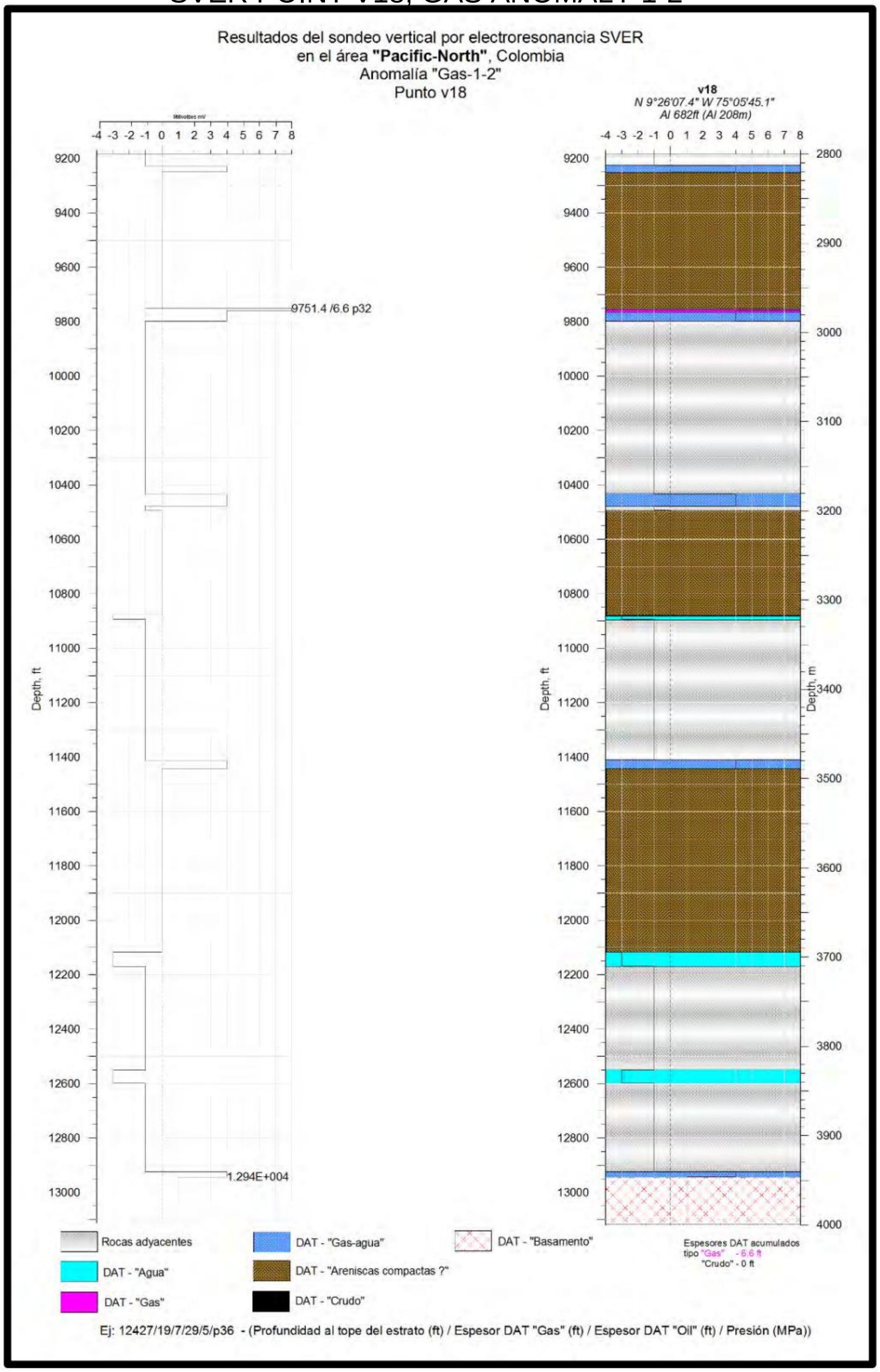
SVER POINT V15, GAS ANOMALY 2-2



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.

ANNEX F

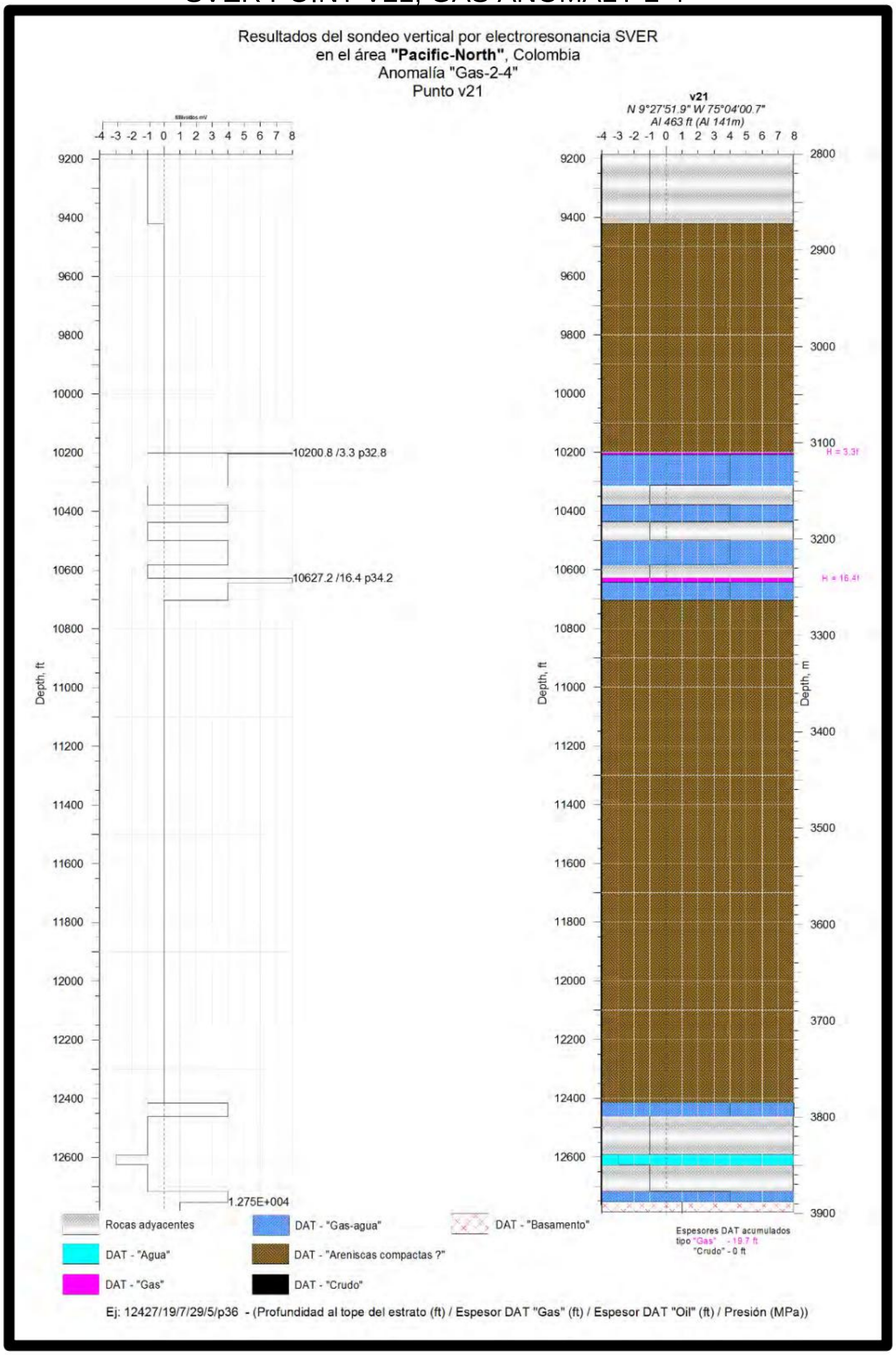
SVER POINT V18, GAS ANOMALY 1-2



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

ANNEX G

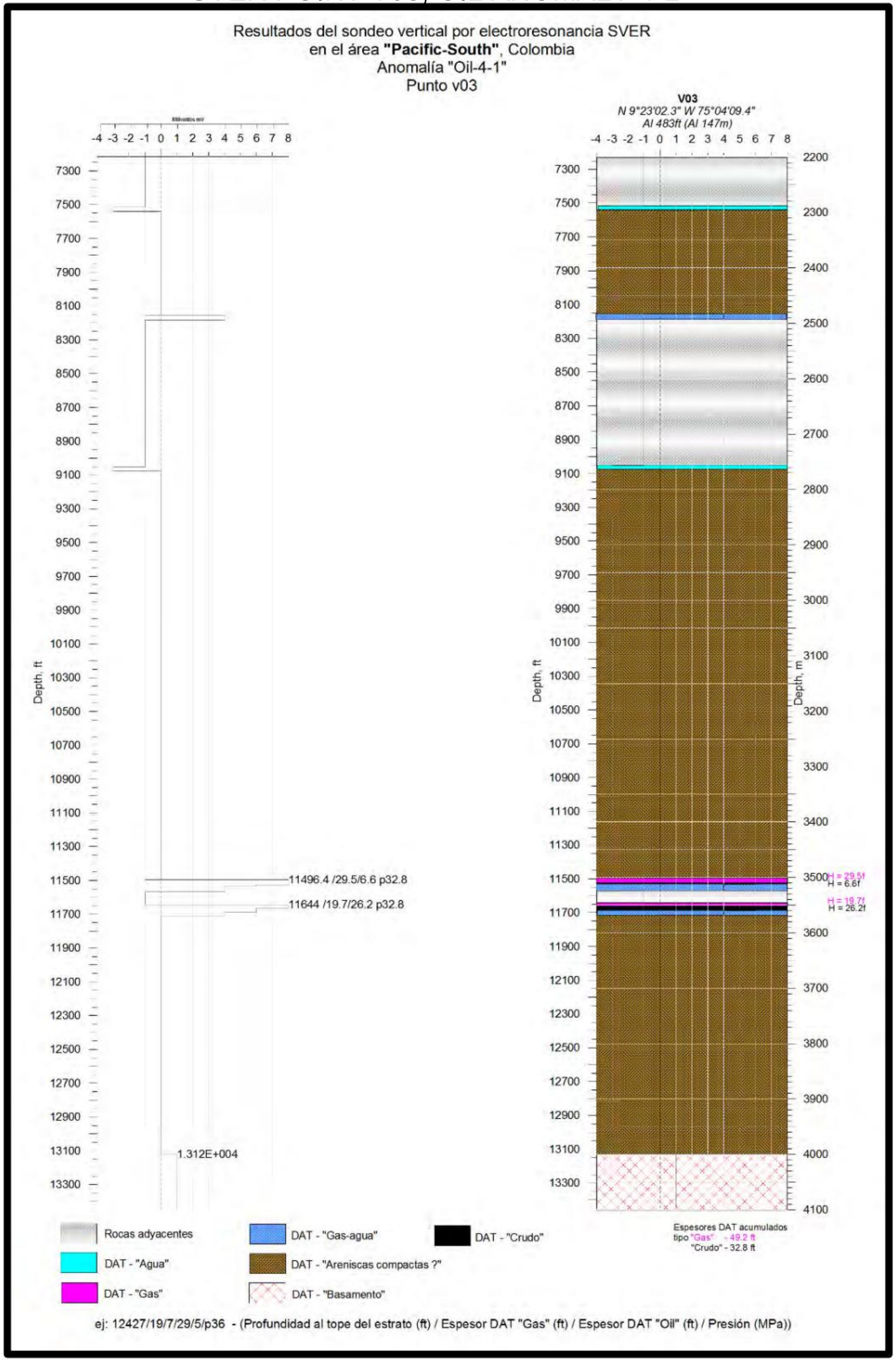
SVER POINT V21, GAS ANOMALY 2-4



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

ANNEX H

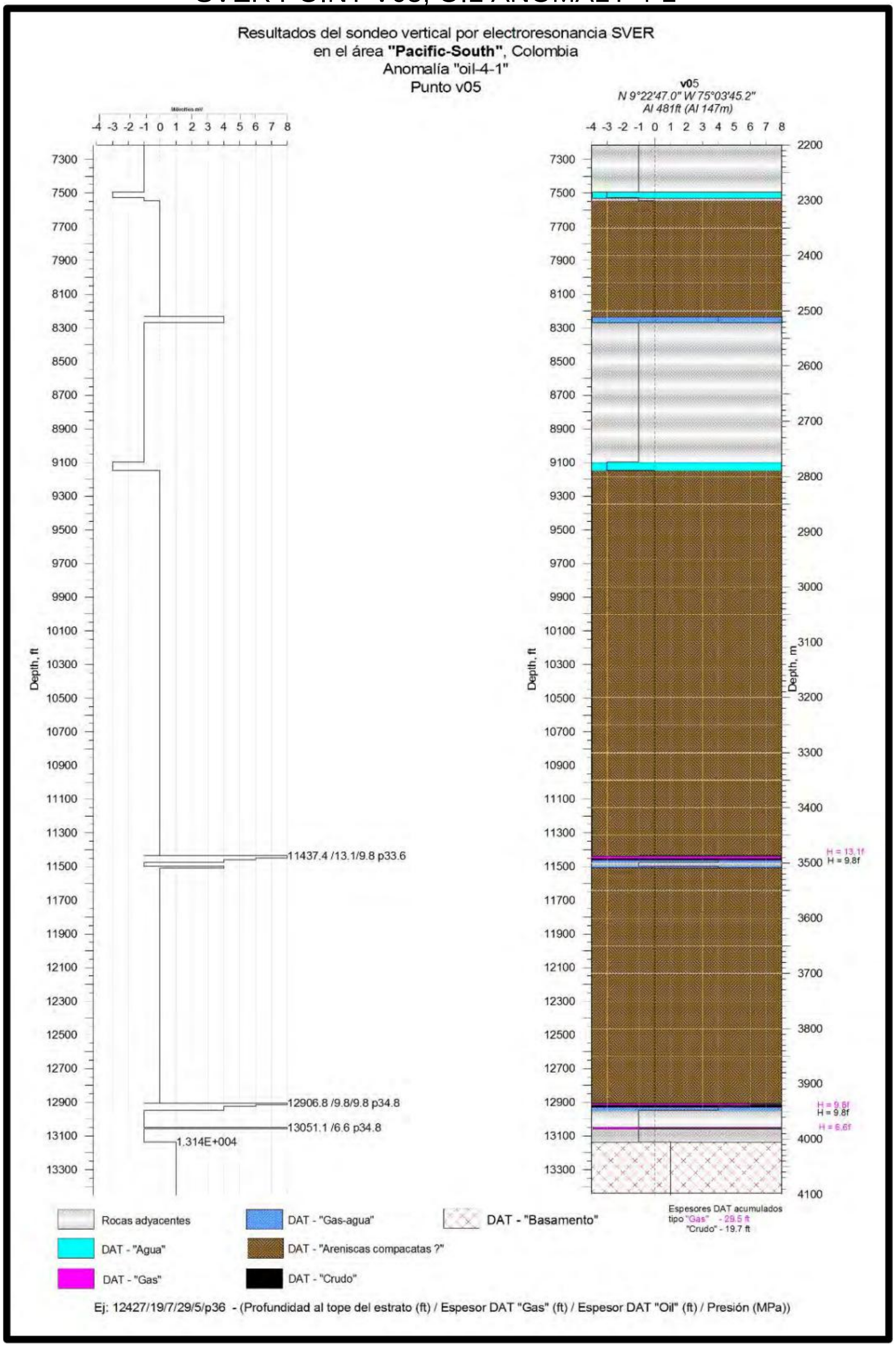
SVER POINT V03, OIL ANOMALY 4-1



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.

ANNEX I.

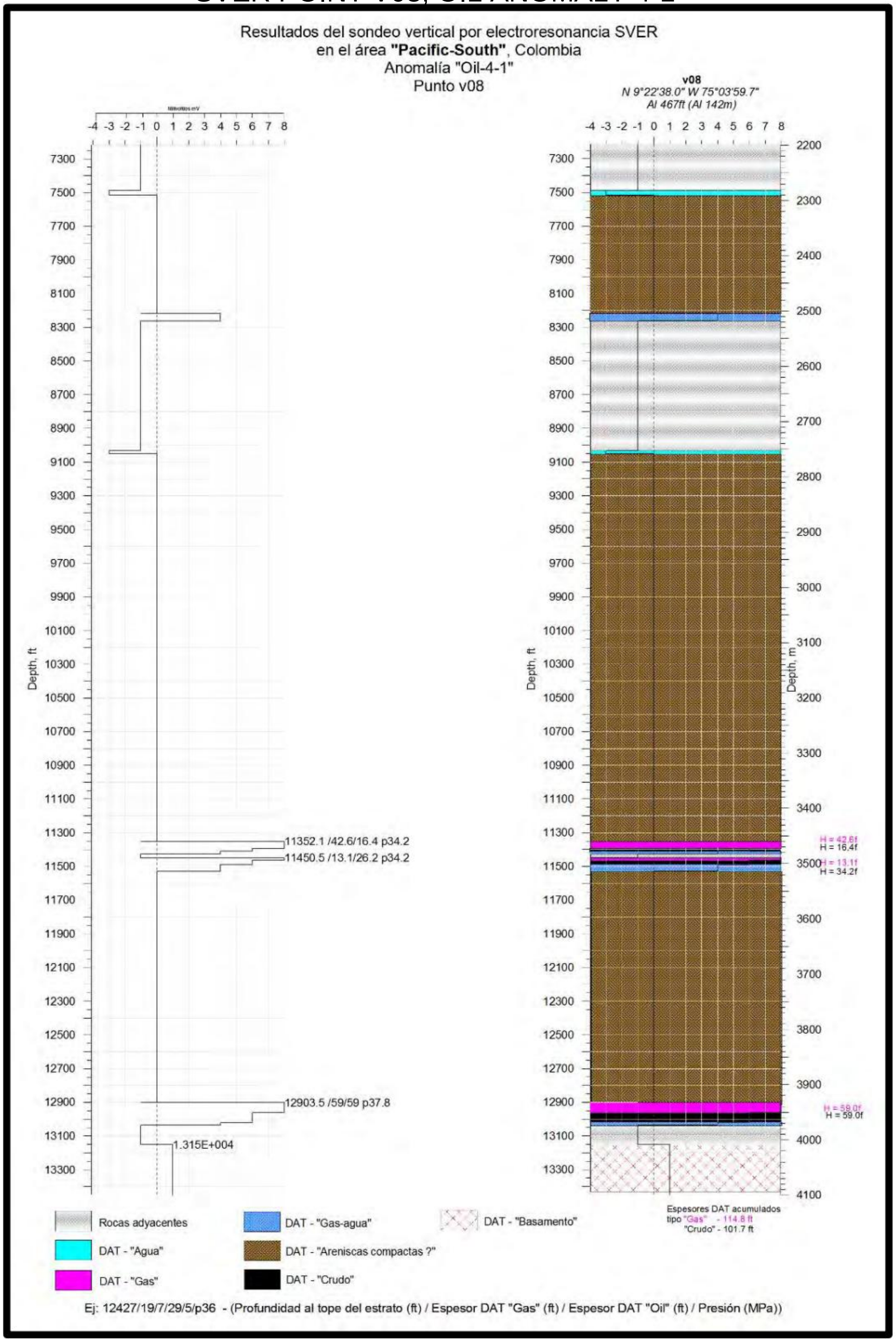
SVER POINT V05, OIL ANOMALY 4-1



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors

ANNEX J

SVER POINT V08, OIL ANOMALY 4-1



Source: CTAC – Advanced Technologies Company of Colombia SAS, La Creciente Field Report, modified by the authors.