

# **Exploration of Hydrocarbons and Mining & Energy Resources Using Non-Seismic Methods - Nuclear Magnetic Resonance Technology<sup>1</sup>**

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**Abstract.** Nuclear Magnetic Resonance-based technology is a geophysical method used in the exploration of hydrocarbons and other mineral resources, by studying electromagnetic signals from natural sources. The foregoing method has three phases: the first phase encompasses the identification of areas where hydrocarbons or other minerals are present at a regional level, using remote sensors; the anomalies identified are studied in detail in the second phase, during which the passive acquisition of electromagnetic signals on the surface with under 30m spacing between points allows demarcating the areas with the highest and lowest intensity, to finally obtain stratigraphic columns at points selected after measuring the basic parameters using Vertical Probing with Electro – Resonance.

The study conducted for Agencia Nacional De Hidrocarburos (ANH) evaluated a total of 1083 Km<sup>2</sup> spread over five areas whose topography, climate and vegetation restricted the acquisition of geological and geophysical data with traditional methods. Two of the five polygons are located in the part of the Chocó basin called Ánimas (163 km<sup>2</sup>) and Istmina (344 km<sup>2</sup>) while Timbiquí (159 km<sup>2</sup>), Remolino (200 km<sup>2</sup>) and Guayacana (217 km<sup>2</sup>) are in the Tumaco basin. The results of the satellite stage included the identification of 178 km<sup>2</sup> of liquid hydrocarbon type anomalies in the Choco basin and 22 km<sup>2</sup> of gaseous hydrocarbon-type anomalies in the Tumaco basin. The anomaly located in Animas was chosen for the field stage. It was detailed by demarcating the areas with the highest and lowest intensity, in which vertical probing took place, allowing for the in-depth characterization of nine parameters (H<sub>2</sub>O, CaCO<sub>3</sub>, Si, C<sub>10</sub> H<sub>22</sub>, CH<sub>4</sub>, C<sub>21</sub>H<sub>44</sub>, Clays, Albite, Anorthite) in up to 4,000 m, identifying intervals showing a significant presence of hydrocarbons at 3,280 ft, 6,950 ft and 12,210 ft with a 36 ft.-average thickness, and an estimated basement depth of 12,650 ft. The correlation with seismic data allowed confirming the results, thus proving that the use of non-seismic methods in exploration and prospection

processes allow for a better understanding of petroleum systems, while reducing uncertainty and exploratory hazards.

**Keywords.** RMN, Nuclear Magnetic Resonance, ANH, Non-Seismic Methods.

## **1. Introduction**

The remote sensing has its beginners in the first series of LANDSAT which was launched in the 70s becoming as the first Earth observation satellite. The development in field over 50 years have taken human beings to advance equipment and tools more sophisticated widening the biotic and abiotic system understanding in the universe.

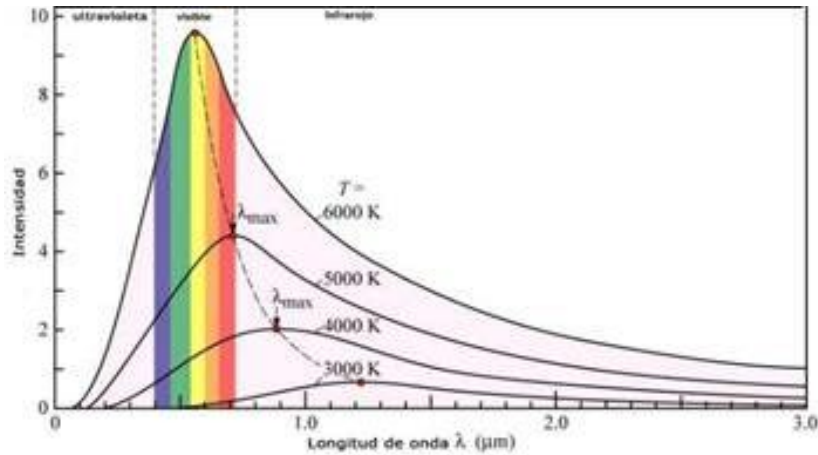
The Space Race between the United States and the Soviet Union brought a vertiginous technology development in both continents and over the pass of the time were getting stronger various sectors, military between them. The use of remote sensors forced countries to reconsider traditional attack, defense and spying concepts. In fact, Russia had advantage either in structure and academy becoming as a global power. After the steel curtain's fall several of discovers and advances during the war came out but it was not until 21st century when was possible to access at the information due to the digital opening given for the Internet.

A relevant aspect in the setting of Russia as global power was the electromagnetism application in economics sectors that allowed resources optimization and increased efficiency in exploration, production and developments process. At this point energy sector was benefited since the technics integration and fundamentals methods in the performance of the electromagnetic waves allowed the real possibility of finding new resources faster and with more accuracy, with these remote perception methods also were offered versatility and facilities.

This marked the beginning of a new era in the hydrocarbon exploration because it started considering electromagnetic prospection as a high value tool in the search for resources, offering the possibility to identify and evaluate zones with extreme conditions without any influence in the accuracy and versatility results nowadays

## **2. Chapter I: Remote Identification for Underground Resources Method**

Planck's law suggests that every physical body no matter its atomic composition emits energy when its temperature is over the absolute zero (-273.15 K). This law describes the electromagnetic radiation emitted for a black body at thermal equilibrium in a certain temperature (see Fig. 1). [1]



**Fig. 1.** Emission curves of black bodies at different temperatures compared to predictions of the classical physics previous to Planck's Law

$$I(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{k\nu T} - 1}$$

The equation (1) is used to calculate the spectral radiance which is the amount of energy that emits a body in function of area units, time and solid angle per unit frequency.

It called emissive power of a body  $E(\nu, T)$  to the amount of radiant energy emitted per area unit and time between the frequencies  $\nu$  and  $\nu + \delta\nu$ . [2]

$$E(\nu, T) = 4\pi \cdot I(\nu, T) = \frac{8\pi h\nu^3}{c^2} \frac{1}{e^{k\nu T} - 1}$$

The wavelength in which is produce a peak in the emission is given for Wien's law; hence as the temperature rises, the brightness of a body is joining wavelengths, this being understanding as a power increase of energy emission measured by Stefan.

Boltzmann's law. [3] This is the integration from the Planck distribution over all the spectral frequencies. This law establishes that a black body emits thermal radiation with a total hemispheric emissive power ( $W/m^2$ ) proportional with the fourth power of its temperature:

$$E = \sigma \cdot T_e^4$$

Where,  $T_e$  is the effective temperature, meaning, the absolute temperature of the surface and sigma is the Stefan-Boltzmann constant ( $\sigma = 5.67 \times 10^{-8} \frac{W}{m \cdot K}$ )

The emissive power of a black body supposes a limit superior for the power emitted by the real bodies therefore the area emissive power of a real surface is smaller than the one of a black body at the same temperature. The equation is:

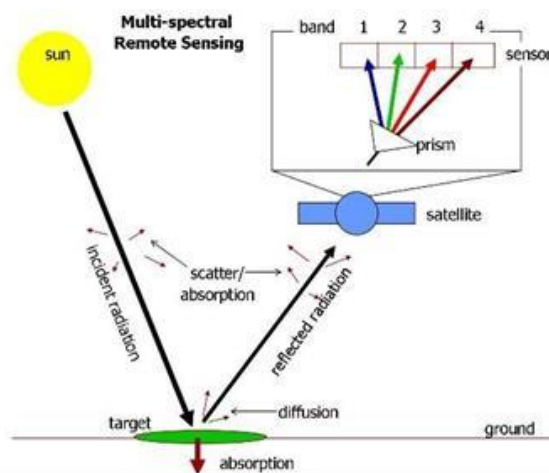
$$E = \varepsilon \cdot \sigma \cdot T_e^4$$

Where,  $\varepsilon$  is a radioactive property of the surface denoted emissivity. With the range of  $0 \leq \varepsilon \leq 1$ , this property is the relation between the radiation emitted per real area and the radiation emitted for a black body at the same temperature. This highly depends on the material, angle, wavelength, and the surface's temperature, typical and specific features for each type of reservoir.

Understanding this, it can be affirmed that every physical body independently of its location on the Earth is in constant energy emission (Spectral sign), feature conditional to the physicochemical properties of the transmitter and the environmental factors that interact with itself.

From this concept, is important to mention the difference between the traditional remote sensing and the satellite prospection, given that the first one is based in the evaluation and description of an electromagnetic wave that interacts with existent bodies on the Earth surface (Reflectance) (see Fig. 2); while the second method integrates different specialized techniques in the elements characterization and identification in function of the intrinsic electromagnetic properties (Emissivity) (see Fig. 1), allowing area delimitation with presence of any interest element even when this located various kilometers in depth.

Likewise, is possible classify the "RMN" method as a no conventional remote perception tool due to the logging information in analog satellite films, it allows to cover a wide range of the electromagnetic spectrum compared to traditional optical electronics ones, in the same way, the procedure consist in the identification of new components product of photoelectric reactions that take place in the films when interact with the energy coming from the interest area. It can be understanding as the developing of the image but that implicated the integration of traditional and advance techniques.



**Fig. 2.** Passive electromagnetic log information reflected.

As was mentioned previously, the environmental factors which an element is exposed likewise its atomic composition define a unique spectral sign and according to what was established for Stefan Boltzmann, the performance of a spectral sign obey essentially at the relation between emissivity and temperature. This two factors are inversely proportional to wavelength which a body emits energy, meaning that the increase in temperature known as the quantity of waves emitted per time unit being the frequency depended to this condition as well.

Even though the spectral signs characterization is a fundamental part of the method, this process is carried through previously to each study and with constant calibration, using laboratory equipment that allow to identify a elementary and compositional level the wavelength and the frequency which the body emits energy. This information is required to the sensor log selection.

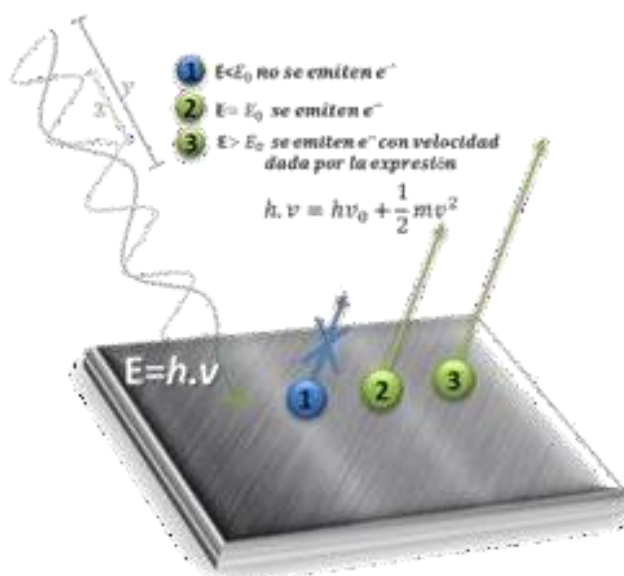
On the other hand, it is important to point out that the used of analog films proposes a solution to the majority of optical electronics sensors constrains that just allow to get tight region from the electromagnetic spectrum. The photoelectric effect explained for Albert Einstein in 1905 in the “heuristic point of view toward the emission and trans- formation of light”, he based his photoelectric formulation as an extension of Max Planck’s job and the quantum theory where Einstein explained that electrons emission was produced for the photon absorption and that was only possible if the waves interacted with a metal in the appropriate frequency to generate a reaction that in principle would have given features for the incident wave. [4]

So in the photo emission process, if an electron absorbs an electromagnetic signal with a higher or equal cut frequency, the electron is ejected from the material but, if the energy of the wave is low, the electron cannot be ejected. The algebraic expression is:

$$hf = hf_0 + \frac{1}{2}mv_m^2 \rightarrow hf = \emptyset + E_k$$

For equation (5), Energy of a photon absorbed = Energy needed to release 1 electron + cinematic energy of the emitted electron. According to the equation,  $h$  is Planck’s constant,  $f_0$  is the cut frequency or minimum frequency of photons in order to the photoelectric effect takes place,  $\emptyset$  is a work function or the minimum energy required to take the electron from the Fermi level to outside of the material. Finally,  $E_k$  is the maximum kinetic energy of the electrons.

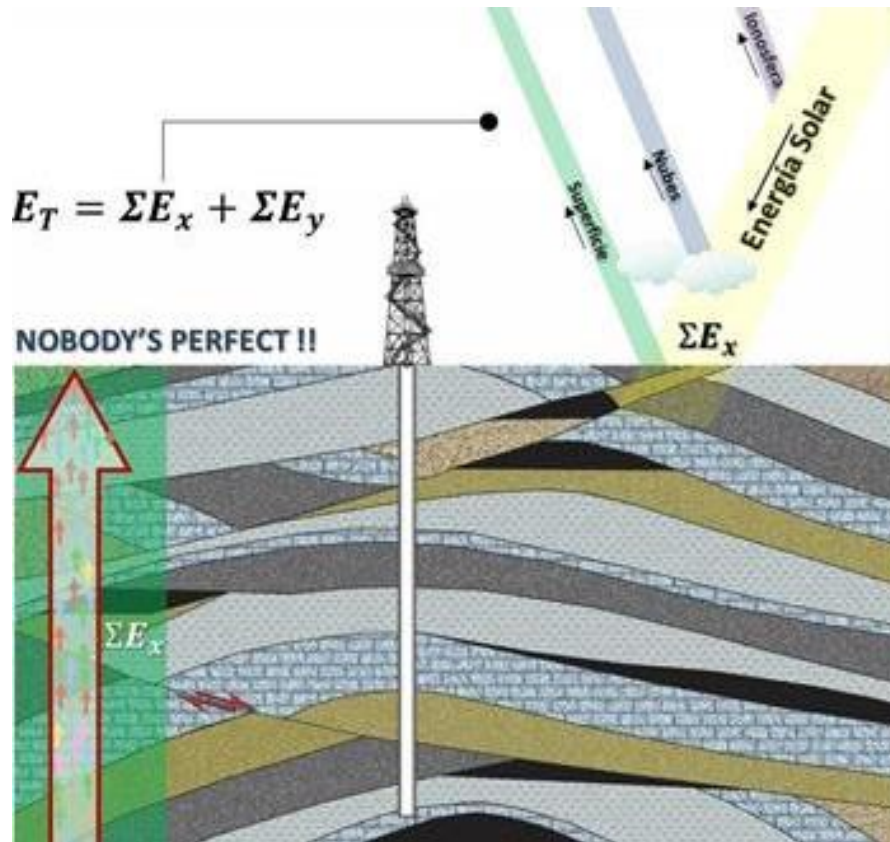
When the wave has appropriated features to generate a photoelectric reaction a photoelectron is released with specific speed and energy (see Fig. 3), likewise the free space is occupied for another electron that as a consequence of the transition emits a photon. The photon with the photons of the incident wave that was not absorb in the process, both constitute the sub products of the equation, however, the consequent re- actions the ones which make possible the log, since the photoelectrons interact with other atoms present in the analog film causing specific physicochemical changes that can be associated indirectly to the waves that generated the photoelectron principle.



**Fig. 3.** Ions liberation with derivate wave's properties that generated the photoelectron reaction.

The new elements become what is denominated as “latent image”, imperceptible to the naked eye but with the electromagnetic information of the area when was expose the film and applying traditional techniques as the orthorectification can be projected over the ground with high precision even when the sensor were various kilometers high.

One of the main features to taking in to account during the film selection is the cut frequency of the constituent elements, this should be lower than the interest element's frequency, likewise the grain size, density and the exposition time condition the quality image, without forgetting that from the emitted energy naturally for the bodies, is added the exogenous energy provided by the sun (see Fig. 4), this makes impossible to quantify the sings exactly that interact with the film lastly. When the corrections are made based on environmental and tool conditions involved during the acquisition, uncertainty decreases before the lab procedure where will be finally delimited the areas with the element presence.



**Fig. 4.** The total energy which the sensor is exposed is the summation between the Solar Energy ( $E_y$ ) and the Endogenous Energy ( $E_x$ )

The Nuclear Magnetic Resonance discovery (NMR) is attributed to Isidor Rabi an Austrian Physics that formulated the magnetic resonance method in 1938. [5] This allowed the magnetic properties and the intern structure of the molecules, atoms and nucleus study, becoming thin worthy of the Novel Prize in Physics in 1944.

The RMN developing divided in 4 fundamentals aspects:

2.1. A Nuclear spin

Some The spin can be understood as the rotation of subatomic particles (electrons, neutrons and protons) on its axis with quantized value, which it means that cannot be found particles with any value instead the spin always will be a multiple of  $\hbar/2$  (where  $\hbar$  is equal to the Planck's constant  $h$  divided by  $2\pi$ ). [6] Meaning that the projection of the electron spin's angular moment is measured in a particular direction given for the external magnetic field, this could result in the unique values:

$$\frac{\pi}{2} \text{ or } -\frac{\pi}{2}$$

From here that the magnetic momentum ( $\mu$ ) is given by the multiplication between a spin different from zero ( $I$ ) and the magnetic spin portion ( $\gamma$ ), being this the constant that indicated the sign intensity for each isotope scanned in the RMN:

$$\mu = \gamma I$$

## 2.2. A Spin performance

A nucleus with  $\frac{1}{2}$ -spin has two possible spins states:  $m = \frac{1}{2}$  or  $m = -\frac{1}{2}$  ( $\alpha$  o  $\beta$ ). The energy of this two states are the identical and in the same way the number of atoms in both should stay in thermal equilibrium, however, if the nucleus is exposed to an external magnetic field, this will cause that both spin states will stop having the same energy, likewise the magnetic momentum of the energy ( $\mu$ ) under the influence of the magnetic field is given for the negative scalar product of the vector as how is expressed in the following equation: [6]

$$E = -B_0\mu = -\mu_z B_0$$

Where E represents the magnetic momentum of the energy,  $B_0$  el external magnetic field and the equation formulates a magnetic field orientation through the axis z.

Therefore, it is possible to conclude:

$$E = -m\hbar\gamma B_0$$

Where  $h$  is equal to the Planck's constant divided by  $2\pi$ ,  $\gamma$  is the magnetic spin portion and  $m$  is the spin.

This means that two spin states with  $\frac{1}{2}$  value are being aligned either in favor or against the magnetic field where, if  $\gamma$  is positive,  $m = \frac{1}{2}$  will be in a low energy state. The difference of energy between both states is produced to a few amount of spins in the low energy state.

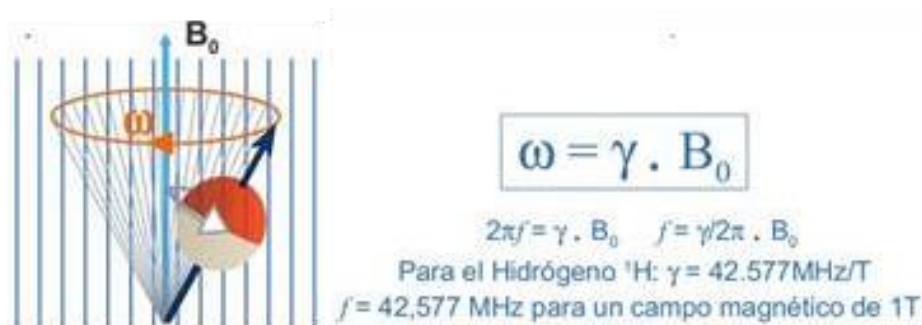
The algebraic expression is:

$$\Delta E = \hbar\gamma B_0$$

The calibration and modulation waves and fields used during the RMN developing are required due to the resonance absorption occurs the energy difference must be stimulated for electromagnetic radiation at the same frequency and that absorption will only occur when:

$$\gamma = \frac{\Delta E}{h} = \frac{\gamma B_0}{2\pi}$$

Where the photon Energy is given for  $E = h\nu$ , being  $\nu$  the frequency of the external wave modulated during the image processing.



**Fig. 5.** Resonance's frequency for the hydrogen atom which magnetic momentum spin is equivalent to 42.577 MHz/T

### 2.3. Nuclear Screening

Modulating and Calibrating the equipment for just one element is not enough, the RMN can be understood as a direct way to the chemical structure of the elements, but it is also influenced and affected for its complexity due to the surrounding electrons generate an effect of "Nuclear screening" which reduce the magnetic field of the nucleus bringing as consequence a decrease of the energy breach and the required frequency to reach the resonance. This far from being a problem, it became in the main reason to create data bases that related the chemical elements and components in function of their resonance frequency and environmental conditions in which they are. In other words, the can be understood as frequency ranges to specific materials identification.

This is a really useful thing in the analog satellite images developing. As it was mentioned before the lab procedure is emphasized in the identification for new elements generated from photoelectrons reaction that afterward it will be associated with the original sign. The RMN allow the identification of one ion to another with high detail expanding the evaluation margin that for study proposes reduces the risk and allow the effective delimitation of interest areas by the superposition of various elements as well as the methane and kerosene for the hydrocarbons' prospection.

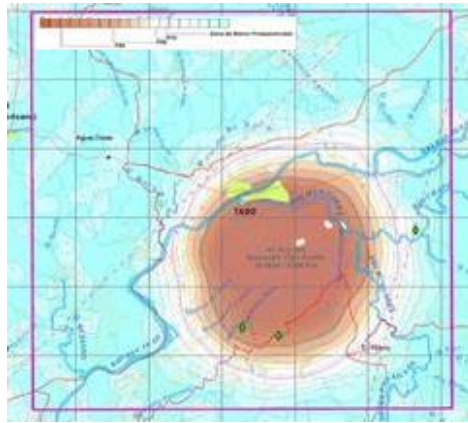
### 2.4. Digitalization

The films' exposition to an external electromagnetic field during a certain period and under stable conditions allows the uniform irradiation of all the elements presented, likewise the stimulation of those which resonance frequency is equivalent to the artificial signal having as consequence the decrease of the rotation angle, increase of the precession speed and spin, and lining up with the external magnetic field.

When the artificial signal is abolished, the elements that were in resonance tend to get back to their natural state realizing grand part of excess energy during the moment known as T2. The digitalization is developed using sensors of adjustable frequency that measured the energy intensity emitted over a surface of the film assigning null values to the zones where the register signal is lower than the base line and the values higher where the intensity increase.

The quantification of the intensity in the films allow the area delimitation with similar features where the higher values suggest larger presence of elements in relaxation state, hence, it can be understood that these new elements are generated from a specific number of photoelectrons resulting of photoelectric reactions. These reactions were caused for a quantity of electromagnetic signal directly proportional to the emitting body volume in a certain point.

The final product is a graphic representation of an interest element and its areal distribution, interpreted from an intensity log in the lab, allowing the classification and area selection with more and less success probability (see Fig. 6).



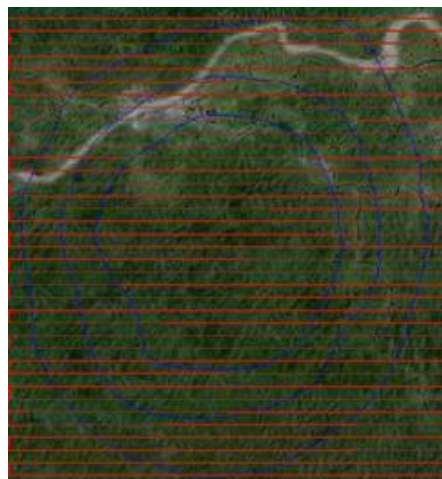
**Fig. 6.** Anomalies Map type for liquid hydrocarbon classified with intensity and cartography integrated.

### 3. Chapter II: Cartography ECECI® of Electromagnetics Anomalies in Situ

The identification of anomalies through remote sensors allow the evaluation of extended areas low price, without intervene, alter and/or affect the environment, however this first phase the main objective is to prioritize and manage the technologic efforts towards those zones with more potential.

The cartography of electromagnetics for the Establishment of Short Impulses Electromagnetic Fields (ECECI®) allow improve the space resolution of the products obtained in during the satellite phase and reduce the uncertainty by the increase of information volume acquired per area unit. [7], [8], [9].

Just as in the satellite phase, the sensor measures the natural radiation coming from the subsoil, then useful signs are filtered allowing the identification of interest elements. Even though travels through the area are made, each measure is individual which permit design flexible acquisition models subject to requirements zone without impact the quality of the results.



**Fig. 7.** Acquisition model for the methane evaluation over satellite anomalies with spacing between lines of 250 meters

The cartography “ECECI®” results refer the distribution of an element in a certain zone, where the increase in intensity signal logged is associated with more interest element concentration. Thus it is possible to classify the area in function of the more or less probability of expected success.

### *3.1. Design Acquisition*

For the design acquisition in a field is necessary to take in to account the land condition, intensity and continuity of the anomalous zone identified previously in the satellite zone, reservoir’s physical and chemical characteristics of interest and general geological information, according to this information it will be determined the data density that will be required and the media transport in function of the displacement speed required.

The spacing between lines for hydrocarbon reservoirs in zone with stable geology can vary from 150 to 250 meters with a spacing between points from 15 to 30 meters allowing to reach a minimum density of 150 data per kilometer squared taking to account that the sampling intervals in the equipment goes from 0.5 to 5 seconds.

For the air and fluvial acquisitions, the maximum displacement speed is 80 Km/h and for the first one the maximum height above the ground is 100 meters which has to be maintained even with changes in the topography guarantying as much is possible the data projection over the surface with less error percentage.

Finally, it must be defined which and how many parameters will be evaluated having the interest reservoir characteristics for each of them, identifying the spectral sign and resonance frequency.

### *3.2. Equipment and Methodology*

The equipment used for the field acquisition weights eight (8) kilograms approximately, is powered by a 12 volts and 14 amperes battery, it has a LCD screen, central unit of processing with storage capacity of 8 Gb, external card unit, GPS integrated system, Analog to digital signal converter and three (3) electromagnetic waves generator of extreme low frequency (Hz), radio frequency (MHz) and high frequency (GHz) that emit and keep an electromagnetic pulse during a period and certain frequency. [10]

Connecting to a unidirectional antenna that acts as a receptor, directing the sensor electromagnetic signals from the subsoil due to the parabolic geometry which according a predetermined time of sampling, it registers and storages the georeferenced signal automatically.

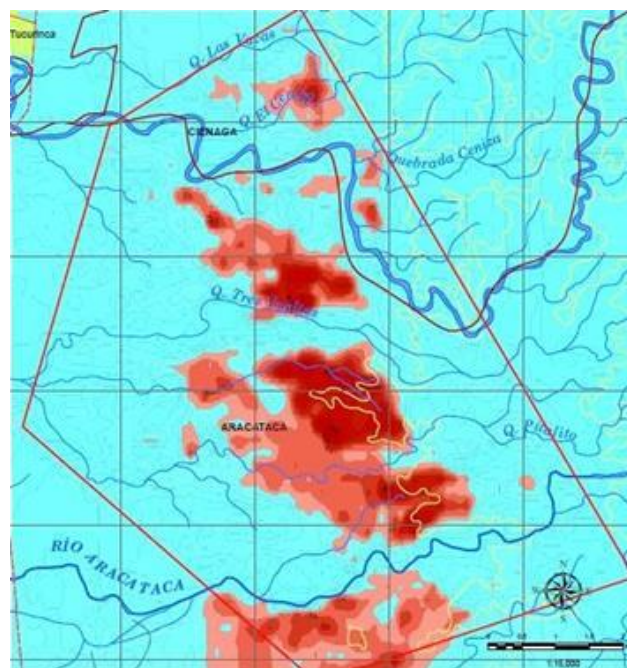
The registered signal is compared to pre-establish patterns for specific frequencies and wavelengths associated for elements and/or compounds, assuming that the acquisition of the useful signal is due to the wave interaction of waves with similar spectral characteristics with those pre-establish for the equipment thus the element presence and/or compound with more or less concentration in some point. This allows to generate intensity maps and delimited with more precision interest areas as those previously mentioned.

The digitalized information is represented graphically and strictly obeyed in the axis X, Y is used to the geographic log location whereas Z belongs to the differential amplitude (mV), this is indirectly related an element and/or compound concentration to a specific spectral sign. It is vital to point out that every singular measurement in which the associated resonance frequency is conditioned to the interest

target. This restricts the identification for elements with different spectral features reducing the uncertainty considerably and delimiting with more precision the evaluation range.

On the other hand, for being independent measurements the direction or order in which the data is acquired is irrelevant if and then the density is maintained and the points sampling distribution allowing to merge different transport media without affecting the original acquisition model.

In fact, what is exported from the equipment are text files, they are charted using specialized software such as Surfer. This allow to generated intensity borderlines that make easier anomalies interpretation and classification as well as other information superposition such as geological maps, cartography, elevation models even ECECI® maps. All this information contributes to the appropriated point selection for depth evaluation.



**Fig. 8.** Superposition Cartography in Anomalies type for liquid Hydrocarbon obtained from ECECI®.



**Fig. 9.** Central unit of processing and logging antenna.

#### 4. Chapter III: Vertical Survey with Electrical Resonance (SVÉR®)

The vertical survey with Electrical Resonance (SVÉR®) is the technology's final component due to it allows the identification of intervals in depth with hydrocarbon presence, lithology identification and mineral and fluids concentration estimation in volume rock without drilling or affecting the subsoil. [11]

The borders generated from the logged information in field with ECECI® suggest the lower and higher concentration of a precise element and/or a compound. However, in the vertical axis is not possible to identify its distribution for that is necessary to make a detail evaluation using the same equipment but modifying the settle and the quantity of register parameters.

The SVÉR® logs can cover as many elements and/or compounds as needed due to each parameter evaluated is independent and bellow to a definite frequency. Hence, the lithology columns interpretation is based on each parameter performance in a certain depth which allow the interpolation between SVERS logs to the developing of tridimensional models and extension and thickness delimitation of a natural or hydrocarbon resource.

##### 4.1. Equipment and Methodology

Different from the ECECI® acquisition, the log of the SVÉR® surveys are made in a specific point adjusting the generators according to the interest elements' resonance frequency.

Each data logged represents the element concentration in a cubic meter, in important to point out that this is a theoretical estimation based in a standard density which can be adjust taking to account the available information of the study area, likewise depth and features of the overlying layer influence directly in the signal's deviation, for that reason control logs and corrections are made to adjust the measures and reduce the error. Vertical Resolution: 1 meter; Error: 5% - 10% for depths from 1 to 4,000 meters and 0.033% approximately for each 100 meters deeper than 4,000 meters; Maxi- mum Evaluation Depth: 10,000 meters.

For a hydrocarbon exploitation study generally is register the parameter with the total hydrocarbon content that includes the whole alkane series ( $C_nH_{2n+2}$ ). However, if a more meticulous study is required, it can be logged individual parameters like liquid alkanes ( $C_{10}H_{22}$ ), solid alkanes ( $C_{21}H_{44}$ ), Methane ( $CH_4$ ) and programmed in the schedule activity. In Table 1. are shown the acquisition parameters used in the field evaluation for a 50  $km^2$  area in the Chocó Basin (ANH-2014).

**Table 1.** Acquisition parameters field phase – Chocó Basin Area ANH-2014)

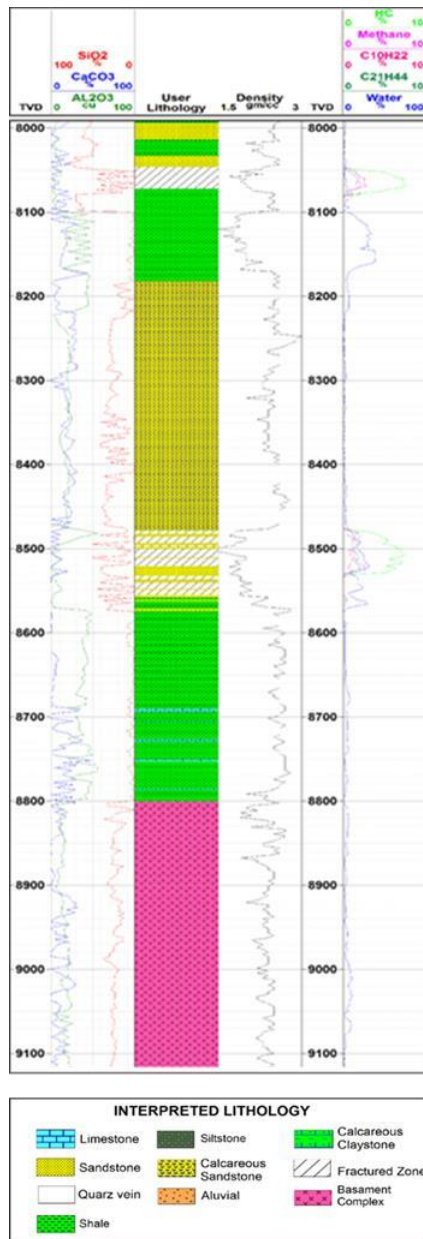
| Acquisition Parameters |                        |                         |                 |
|------------------------|------------------------|-------------------------|-----------------|
| Spacing                |                        |                         |                 |
| Acquisition Lines (m)  | Acquisition Points (m) | Material Target         | Media Transport |
| 200                    | 25                     | $CH_4$ , $C_{10}H_{22}$ | Aerial          |

| <b>Acquisition speed<br/>(km/h)</b> | <b>Height flight<br/>(m)</b> | <b>Sampling Time<br/>(Seconds/data)</b> | <b>Polygon Geometry</b> |
|-------------------------------------|------------------------------|---|-------------------------|
| 100                                 | 100                          | 2.5                                     | Rectangular             |

Once it is settled the log parameters, the study frequencies are defined. The field phase principle is based in the no intrusive reception of natural electromagnetic fields and the extraction of a useful signal from the electromagnetic noise by the stochastic resonance phenomenon.

The equipment used for geophysical studies is an electronic portable device approximately 8 kg weight with 3 electromagnetic wave generators:

1. High frequency generator in the 100 to 3,000 MHz interval – to determine the study substance presence in the rock.
2. Radio frequency generator in the 2 to 30,000 m wavelength interval – to determine the reservoir depth of the study substance
3. Low frequency generator in the 0.5 to 30 Hz interval – for cartography failures.

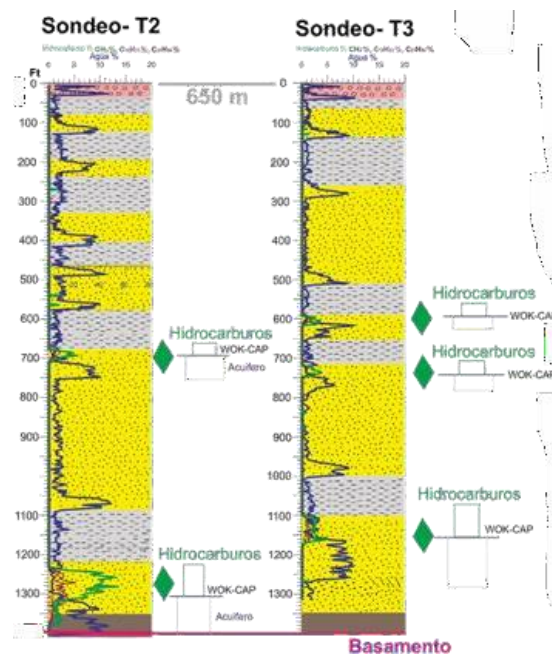


**Fig. 10.** Interpreted Lithology from SVER® log.

This equipment has a processor, its memory, it integrates a GPS antenna, port for computer and battery for 7-8 hours in automatic function. The equipment has a directional electric antenna to receive circular polarization signals (electromagnetic noise of the Earth).

The processing of the logged data allows to identify the maximum concentration in each measurement point without defining or relating in a detailed way the anomalies distribution of the study area. Knowing the occurrence of a mineralization, the presence of a recourse in depth in the initial exploration phase is mainly one of the biggest challenges searching for resources. [12] Current technologies as RMN allow to recognize the distribution and the detail limits of the resource. It allows to identify on surface its presence in depth through the vertical surveys for electrical resonance.

Particularly, logging and processing acquired data in each survey allow to know not only the resources composition and thickness but also the lithology sequence present in the vertical section, the conventional parameters acquired to rocks identification such as  $SiO_2$ ,  $CaCO_3$ ,  $Al_2O_3$ , flus and hydrocarbons like  $C_{10}H_{22}$ ,  $CH_4$ ,  $C_{21}H_{44}$ ,  $H_2O$ , even if there are a particular interest knowing water salinity, chloride can be logged  $Cl^-$ , sulfates ( $SO_4$ ), sodium chloride ( $NaCl$ ), iron ( $Fe$ ). Depending on acquired surveys density and its systematic distribution, it is possible to make geological sections and tridimensional models for the reservoir or a particular layer. This information integrated with geological and geophysical information of the area will allow to define more correct geological models and decreasing the exploratory risk for any resource.



**Fig. 11.** Interpreted lithology from obtained information with SVER®, contacts estimation and basements correlation

## 5. Another Chapter IV: Case of Study in the National Hydrocarbon Agency (ANH), Choco and Tumaco Basins.

In the study developed for the Agencia Nacional de Hidrocarburos (ANH) was evaluated 1,083 km<sup>2</sup> in total distributes in five zones where the topography conditions, weather and vegetation were a limitation for the geological information and geophysical acquisition with traditional methods. Two out of five polygons were located in the Chocó Basin known as Ánimas (163 km<sup>2</sup>) e Istmina (344 km<sup>2</sup>) while Timbiquí (159 km<sup>2</sup>), Remolino (200 km<sup>2</sup>) y Guayacona (217 km<sup>2</sup>) were located in Tumaco Basin.

It is important to point out that the Results obtained from satellite phase allowed the identification of 178 km<sup>2</sup> anomalies type of liquid hydrocarbon in the Chocó Basin and 22 km<sup>2</sup> anomalies type of gaseous hydrocarbon in the Tumaco Basin. For the field phase the anomaly located in the Aminas area was selected to detail to delimit zone with more and less intensity where vertical surveys allowed characterization in depth until 4000 meters for nine parameters ( $H_2O$ ,  $CaCO_3$ ,  $SiO_2$ ,  $C_{10}H_{22}$ ,  $CH_4$ ,  $C_{21}H_{44}$ , limestone, Albite, Anorthite) identifying intervals with significant hydrocarbon presence at 3,280 ft, 6,950 ft y 12,210 ft with average thickness of 36 ft, besides the basement depth was estimated at 12,650 ft.

The correlation with seismic information allowed the validation result demonstrating that including no seismic methods in process of exploration and prospection allow a better understanding of oil systems decreasing uncertainty and exploration risk.

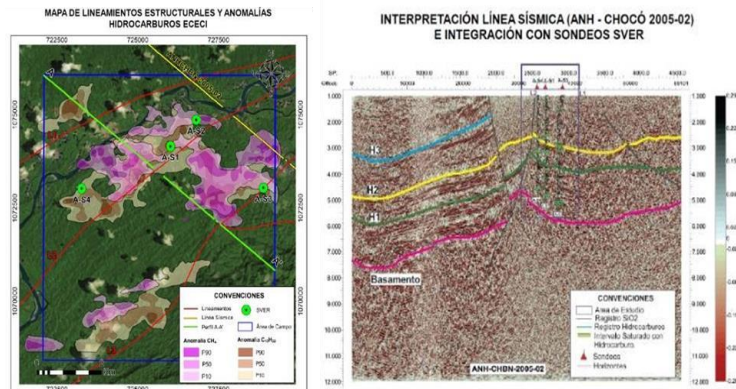


Fig. 12. Result correlation with seismic and geological information.

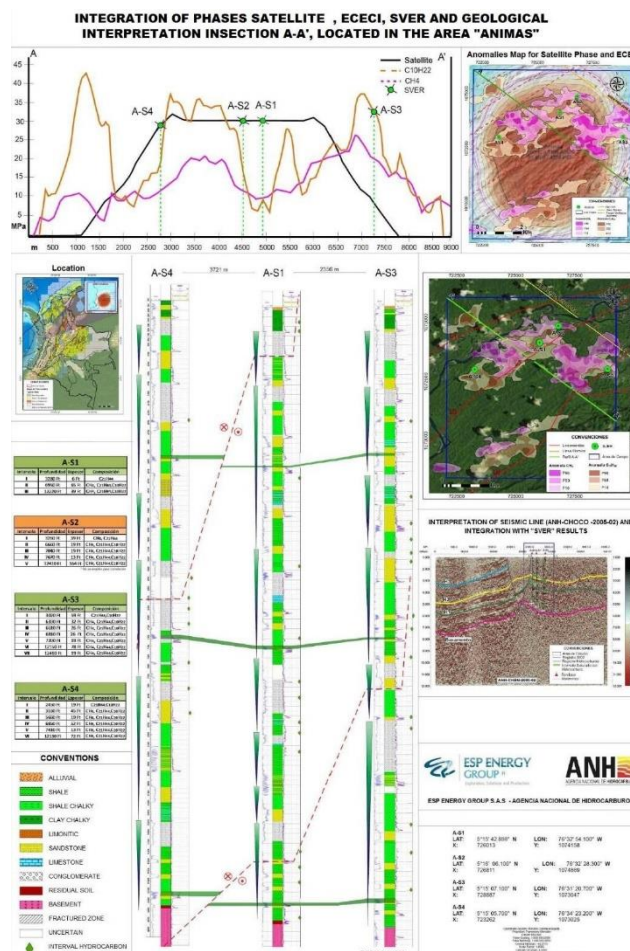


Fig. 13. Integration Poster with satellite results, ECECI® y SVÉR®.

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