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Possible gaso-petroleum occurrence from non-seismic and non-conventional exploration methods in the Central Basin, Cuba

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Abstract
In various geological situations, seismic data provides little information about whether a trap contains hydrocarbons. It is well documented that the generality of hydrocarbon accumulations has predominantly vertical microfiltration. The use of non-seismic and non-conventional exploration methods, integrated with geological and seismic data, enables a better evaluation of prospects and exploration risk; such is the purpose of the investigation. The general objective was to map possible new gaso-petroleum targets that support exploration in the study region. The cartography of the areas of interest would be based on the presence of the indicator anomalies: gravimetric, aeromagnetic and airborne gamma spectrometric. In addition, a 2D model of the potential fields of the Jatibonico oilfield was designed to validate the hypothesis that the magnetic maximums reduced to the pole are the cartographic expression of the continental margin carbonate uplifts. The results indicate that the anomalous complex of the Cristales oilfield is reproduced in the location of La Vigía, which manifests as a preserved occurrence, according to the results of recognition by the ***Redox Complex***.

Keywords: oil hydrocarbon exploration; non-seismic and non-conventional exploration methods; gravimetry; aeromagnetometry; airborne gamma spectrometry; *Redox Complex*.

Posible ocurrencia gaso-petrolífera mediante métodos de exploración no sísmicos y no convencionales en la Cuenca Central, Cuba

Resumen
En diversas situaciones geológicas, los datos sísmicos aportan poca información acerca de si una trampa contiene hidrocarburos. Está bien documentado que la generalidad de las acumulaciones de hidrocarburos tiene microfiltraciones predominantemente verticales. El uso de los métodos no sísmicos y no convencionales de exploración, integrados con datos geológicos y sísmicos, posibilita una mejor evaluación de los prospectos y del riesgo de exploración; tal es el propósito de la investigación. El objetivo general fue el de cartografiar posibles nuevos objetos gasopetrolíferos que fundamenten la exploración en la región de estudio. La cartografía de las áreas de interés se realizaría a partir de la presencia de las anomalías indicadoras: gravimétricas, aeromagnéticas y aerogammaespectrométricas. Además, se diseñó un modelo 2D de los campos potenciales del yacimiento Jatibonico para validar la hipótesis de que los máximos magnéticos reducido al polo, son la expresión cartográfica de levantamientos de los carbonatos de margen continental. Los resultados indican que el complejo anómalo del yacimiento Cristales se reproduce en la localidad La Vigía, la cual se manifiesta como una ocurrencia preservada, según los resultados del reconocimiento por el ***Complejo Redox***.

Palabras clave: exploración de hidrocarburos; métodos no sísmicos y no convencionales de exploración; gravimetría; aeromagnetometría; aerogammaespectrometría; ***Complejo Redox***.

1. Introduction

The seismic exploration is insurmountable to provide structural and stratigraphic information, as well as for the cartography and the obtaining of images of traps and hydrocarbon reservoirs. However, in various geological

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situations, seismic data provide little or no information about whether a trap is loaded with hydrocarbons. In other cases, when the acquisition is difficult and extremely expensive, or the quality of the information is poor due to the geology or unfavorable surface conditions, it is the non-seismic exploration methods and, in particular, the unconventional methods of exploration, the only ones that can provide information on subtle stratigraphic traps. Also, it is well documented that the generality of hydrocarbon accumulations has leaks or microseepage, which are predominantly vertical, and that they can be detected and mapped using various non-seismic and non-conventional exploration methods.

The surface expression of hydrocarbon microseepage can take many forms, which determine the development of various detection methods, both direct (hydrocarbon gas geochemistry) and indirect (***Redox Complex***), as well as non-seismic geophysical methods (gravimetric, magnetic, electrical and airborne gamma spectrometric), morphometric and remote sensing.

The benefits in the use of non-seismic and non-conventional exploration methods [9, 10], integrated with geological data and seismic, translate into a better evaluation of prospects and exploration risk; such is the purpose of the present investigation.

The Central Basin of Cuba has been studied for prospective oil purposes since the 1930s by North American companies that discovered the Jatibonico (1954), Cristales (1955) and Catalina (1956) oilfields [7]. Subsequently, in the year 1990, the Pina oilfield was discovered. This region constituted for many years one of the main petroleum areas of the country. Up to the present, the findings have been confined to effusive-sedimentary rocks, or to sediments deposited during the Cuban Orogeny, at depths never greater than one kilometer. However, geochemical studies show the existence of, at least, two petroleum systems, whose generating sources could be found under the igneous varieties of the Cretaceous Volcanic Arc (CVA) [3]. In such a case, it can be assumed that at greater depths, even comparable accumulations could appear, due to their volume, to those currently being exploited on the north coast of the provinces of Habana, Mayabeque and Matanzas [12].

The general objective of the research is: to establish perspective sectors for hydrocarbons in the Block 21 region around the Jatibonico, Catalina and Cristales oilfields. As specific objectives, we have:

- To process and interpret the gravimetric and aeromagnetic fields at 1:50000 scale, the airborne gamma spectrometry (AGS) at scale 1:100000 [8] and the Digital Elevation Models (DEMs) 90x90m and 30x30m of the territory [13].
- To establish the possible presence of hydrocarbons in the depth and the general characteristics of each of the possible occurrences, from the use of non-conventional geophysical-geochemical techniques of indirect detection exploration (***Redox Complex***).
- To establish the relationship of the possible occurrences with the Jurassic-Cretaceous carbonates, from the 2D modeling of the potential fields.

1.1. Geographical location and general characteristics of the study region

The study area includes the region of Block 21 in the neighborhood of the Jatibonico, Catalina and Cristales oilfields, in the Ciego de Ávila province.

The Jatibonico oilfield was discovered in 1954 from gravimetric data, as well as the location of the Cristales fault, however, the Catalina structure was revealed from the first seismic investigations carried out in the region (1955-1956).

In the 1960s, the Central Basin area was the largest petroleum producing region in the country, which brought with it an accelerated development of exploration works, which have been extended by more than 50 years of research and development. However, after the decade of the 90 'with the discovery of the Pina oilfield, there has not been another finding of importance in the region.

The geological model for the study area, according to Martínez Rojas et al. (2007), considers reservoirs of the tuff, sandstone and tobaceous conglomerate type, associated with the CVA, and its seal, argillaceous sequences of the synorogenic cretaceous and postorogenic (Maastrichtian-Lower Eocene) coverage.

For the establishment of sectors of oil and gas interest in this region, it has been considered essential to characterize the non-seismic anomalous complex of the Cristales oilfield, the most general one, since the Jatibonico oilfield presents a very particular anomalous picture. The response pattern of the Cristales oilfield shows, from a set of non-seismic attributes, the presence of the following indicator anomalies Fig. 1.:

- Very subtle local gravimetric maximum (from the first vertical derivative or the residual at 500m), which reflects a positive structure, presumably by the lifting of the denser volcanics.
- This maximum is located within the limits of the contours of the aeromagnetic field reduced to pole (RP) in the interval between -220 and -75 nT and, with presence, in the proximity, of a local magnetic maximum greater than -75 nT, which defines, apparently, an area with presumable uplift of volcanic rocks.
- Minimum of the K/Th relation, with local maximums of U (Ra) in its periphery.
- Absence of geomorphic anomalies.

A summary of the most general characteristics of the Cristales oilfield, according to Linares et al. (2011), is offered below:

Deposits in raised folds associated with the limestones, top of tuffs, conglomerates and lenticular tobaceous sandstones. The relationship between the producing zones and the Cristales fault is recognized. The volcanic section is conventionally divided into layers A, B, C and D. Layers B and C are indicated as the best producers (the most fragmented), located above the horizon of "hard tuff"

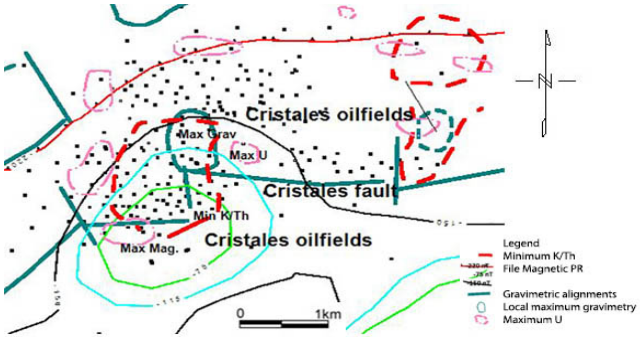

Figure 1. The response pattern of the Cristales oilfield. Source: The Authors.

(diabases, spilites, basalt porphyrites), defined as layer D. This last horizon has been producing in some wells of the oilfield and it varies in depth in the three blocks presents. To the north, it is discovered between 1500 and 1700 m, in the Central Block it occurs over 1000 m and in the south around 1200 m.

The oils, of a good quality (20-30°API), present variations in their physical-chemical properties, which are expressed as follows: density at 20°C from 0.8528 to 0.9483 g/cm^3; sulfur content from 0.58 to 1.34%; Asphaltene content from 0.1 to 2.0%; Resin content from 2.6% to 19.4%. The study of the biomarkers shows that they were generated by a carbonate-clay rock, deposited in a marine environment, subanoxic with contribution of marine organic matter. The physical-chemical properties of these oils vary due to the effect of biodegradation, the heavier oils being generally in the horizons closest to the surface.

The geological task posed to the geological-geophysical processing and interpretation consisted in the mapping of possible new gaso-petroleum targets that will base the oil exploration in the region of Block 21, in the surroundings of the Jatibonico, Catalina and Cristales oilfields. In addition, an evaluation of the possible new mapped targets was envisaged through recognition work by the ***Redox Complex***. The mentioned cartography was proposed to perform from the presence of a complex of non-seismic indicator anomalies, mainly gravimetric, aeromagnetic and airborne gamma spectrometric. For such purposes, the gravimetric and aeromagnetic fields at 1:50000 scale, the AGS at scale 1:100000 and the DEMs 90x90m and 30x30m of the territory were processed.

On the other hand, it was considered that from the 2D modeling of the gravimetric and magnetic fields it was possible to verify the hypothesis that the magnetic maximums reduced to pole (RP) greater than -75 nT are the cartographic expression of uplifts of the continental margin carbonates.

2. Materials and methods

2.1. Information, its sources and processing

The materials used and their sources are the following: Gravimetric and aeromagnetic field meshes at 1:50000 scale and, airborne gamma spectrometric (channels: It, U, Th and K) at 1:100000 scale of the Republic of Cuba [12]. DEMs 90x90 m and 30x30 m from the Republic of Cuba [13] and https://lpdaac.usgs.gov/), respectively. Digital Map of the Oil Wells of the Republic of Cuba at scale 1:250000 and Map of the Oil manifestation of Cuba at scale 1:250000 [1, 2].

The processing of the geophysical-morphometric information was carried out using the software Oasis Montaj version 7.01.

The gravimetric field (Bouguer reduction, 2.3t/m^3) was subjected to the regional-residual separation from the Upward Analytical Continuation (UAC) for the heights of 500, 2000 and 6000 m, given by the order of depth of the possible oil and gas targets; to the first vertical derivative (VD) and, to the total horizontal derivative (THD). The probable targets of interest are characterized by subtle local maximums, within the regional minimum of the basin, close to regional faults of the Cristales type, expressed in VD and THD.

The aeromagnetic field was subjected to the reduction to pole, to the regional-residual separation to 500 m and the VD, seeking to map the trend of values between -220 and greater than -75 nT, associated with the possible regional structural uplift of the volcanic rocks. It was also determined the inclination derivative of the magnetic field RP [4] with the purpose of establishing the depth of the magnetic targets with intensity greater than -75 nT, linked to the top of the volcanics, in or near the non-seismic anomalous complexes of interest.

For the AGS, the K/Th ratio was determined, indicating the minimums surrounded by maximums (presumably linked to active zones of light hydrocarbon microseepage) and the local maximums of U (Ra) at their periphery.

The maps of residual anomalies from the UAC at 500 m for the DEMs 90x90m and 30x30m were used to evaluate the possible presence of positive geomorphic anomalies within the different non-seismic anomalous complexes.

The 2D modeling of the potential fields offers a satisfactory solution (not without ambiguity) to the deep constitution of a territory, especially in cases where the depth of the seismic study is limited by the presence of a volcanic section. The preparation of the model was carried out assuming the simplification of the rocky complexes present in the study section Table 1, where the following convention was adopted:

- On the basement there are sediments of the synrift that fill the irregularities of its relief, so they will not be considered, assuming a flat surface.
- In the territory of study, the evaporite rocks of the Upper Jurassic are very subordinate, or nonexistent, so they will not be considered in the study section.
- In this way, only a packet of carbonate rocks is conceived on the basement and, above them, the CVA (Tuff + Effusive) with its ophiolitic basement, covered by syn- and postorogenic sediments.

Table 1.
Physical properties for the 2D modeling of potential fields in the Jatibonico-oilfield, Central Basin, Cuba.

Geological Unit	Density [t/m^3]	Magnetic Susceptibility [10^{-3} SI]
Syn- and Postorogenic Sediments	2.38-2.45	0.2
Tuff	2.45-2.60	5.0
Effusive	2.57-2.65	8.7
Serpentinite	2.63-2.70	8.0-24.0
J-K Carbonate	2.57-2.65	0.03
Basement	2.65-2.75	6
Moho	3.3	--

Source: [9].

3. Results and discussion

3.1. Results of non-seismic and non-conventional methods

The results of the complex interpretation of the non-seismic methods of the study region are presented in Fig. 2. In this figure with gray-green tracings, the local gravimetric maximums and tectonic alignments by gravimetry are shown. In strokes: red, black and light green the values: -220, -150 and -75 nT, respectively, of the magnetic field reduced to pole. In thick red stroke, the minimums of the K/Th ratio are indicated and, in pink, the increments of U (Ra). The recognition profiles of the ***Redox Complex*** made (La Vigía and El Trabuco) are indicated in blue lines and, those projected in other anomalous complexes, in fine black lines. Drilling wells (black dots) are also observed.

In Fig. 2. the Catalina oilfield is not identified by any anomalous complex, being able to be recognized only in the residual map at 500 m of the magnetic field RP Fig. 3.

The results of investigations with non-seismic and n

on-conventional methods in the study region indicate that the anomalous complex of the Cristales deposit Fig. 1. is reproduced in one of three recognized locations: La Vigía. This target, with an area of 5-15 km^2, and a probable depth of close to 1000 m or less, is associated with a presumably feeder fault to the north and parallel to the Cristales fault Fig. 4.

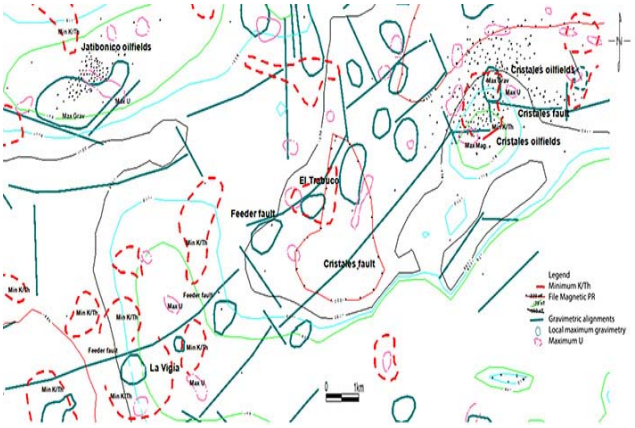

Figure 2. Results of the complex interpretation of non-seismic methods in the region of Block 21, in the neighborhood of the Jatibonico, Catalina and Cristales oilfields.
Source: The Authors.

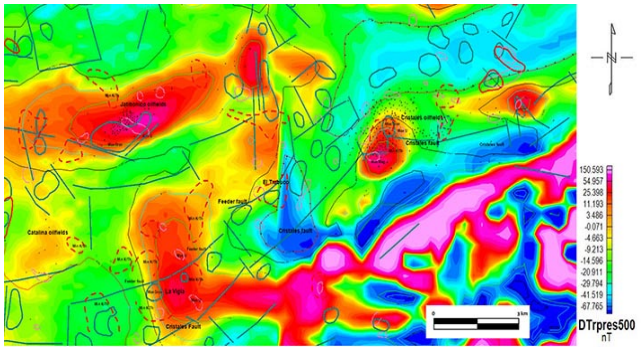

Figure 3. Residual RP magnetic field at 500 m of the study territory.
Source: The Authors.

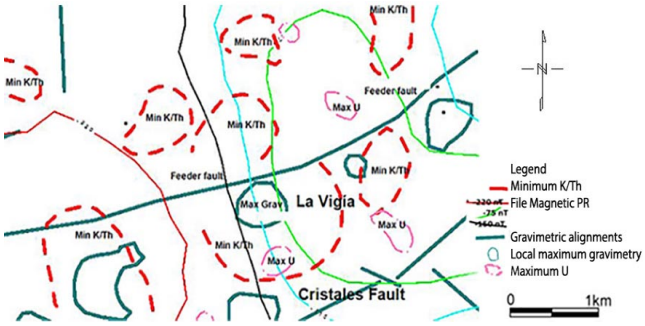

Figure 4. Non-seismic anomalous complex in the location of La Vigía. Detail of Fig. 2.
Source: The Authors.

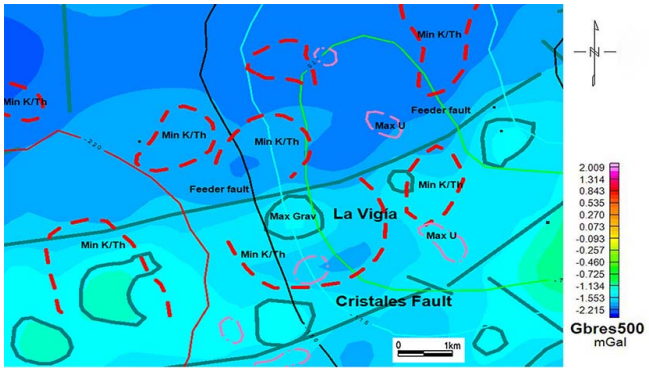

Figure 5. Residual gravimetric map at 500 m from the location of La Vigía.
Source: The Authors.

Residual gravimetry at 500 m Fig. 5. reveals a local maximum less than 0.5 mGal south of the presumably feeder fault (which we will call the same name, La Vigía) and a slight increase north of it, coinciding with a minimum of the K/Th ratio Fig. 7. This reveals the existence of a more sunken block north of the mentioned fault.

The aeromagnetometry of the sector Fig. 6. reveals a magnetic RP maximum greater than -75 nT of longitudinal course, which covers the southern and northern part of the La Vigía fault. An estimate [4] of the depth of this magnetic target (top of the volcanic) gives a figure of 600-800 m, similar with the 600-800 m for the magnetic maximum of

Cristales oilfield and, the 300-500 m for the magnetic maximum of Jatibonico oilfield. This suggests that the possible occurrence has, in the south block, a depth analogous to that of the Cristales oilfield (in the order of 1000 m or less).

The AGS, from the K/Th ratio Fig. 7., reveals two minimums, one of greater proportions in the south block and another smaller one in the north block; both probably related to the same occurrence, resulting in a total area of 5-10 km^2. Two other minimums, to the north and west of the last mentioned, could also be involved, which would increase the area of possible occurrence in another five km^2 (15 km^2 in total).

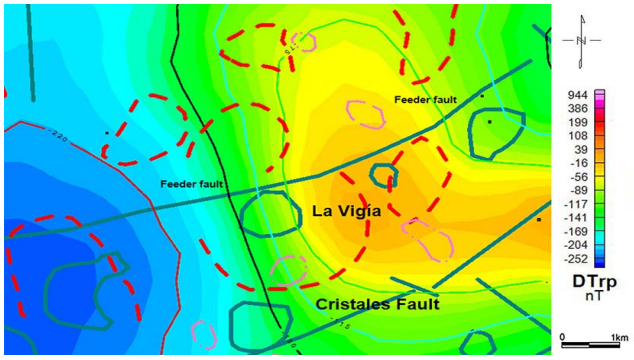

Figure 6. Aeromagnetic map reduced to pole of La Vigía locality.
Source: The Authors.

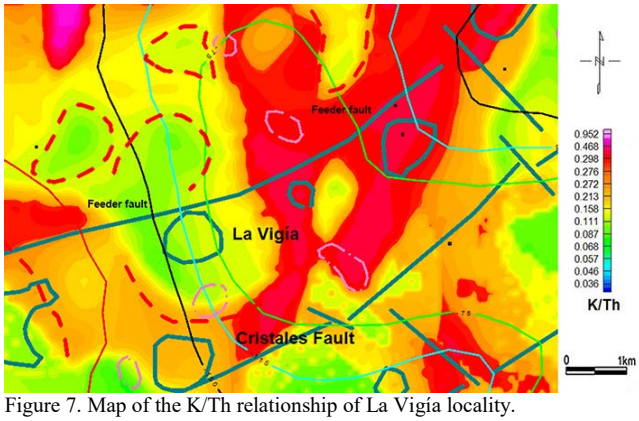

Figure 7. Map of the K/Th relationship of La Vigía locality.
Source: The Authors.

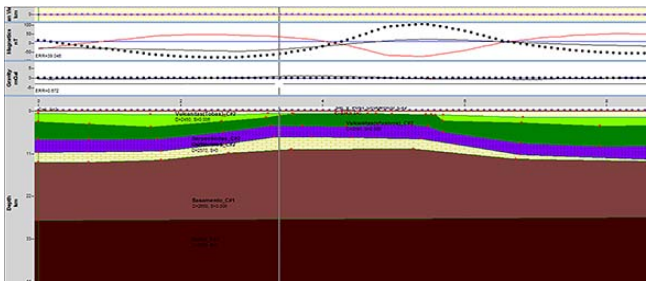

Figure 8. 2D model of the Jatibonico oilfield from the potential fields with gravimetric mean square error of 0.67 and magnetic mean square error of 39.04.
Source: The Authors.

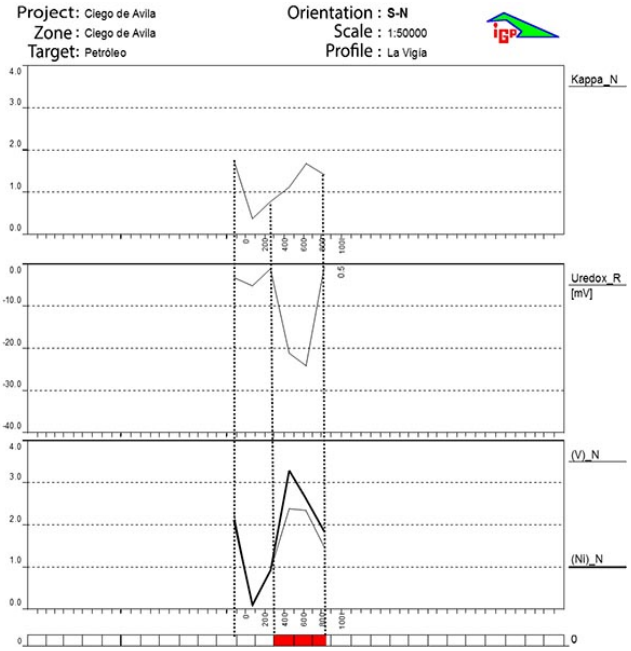

Figure 9. Results of the works by the ***Redox Complex*** in the location of La Vigía. The distance between observation points is indicative.
Source: The Authors.

In order to evaluate the hypothesis about the deep origin of the volcanic uplifts in the Jatibonico, Catalina and Cristales oilfields, as well as in other sectors of interest, such as La Vigía, the potential fields on the Jatibonico oilfield were modeled. There, is where only well information is available up to 4000 m. According to their results Fig. 8., the regional magnetic maximums RP greater than -75 nT can be a cartographic expression of uplifts of the continental margin carbonates and its basement. On the other hand, the thickness of ultramafites can be approximately of 3000 m, being the carbonates J-K to a depth approximated of 6000-7000 m, with a thickness of approximately of 3000 m.

The results on the gaso-petroleum nature evaluation of the non-seismic anomalous La Vigía complex, from the recognition works by the ***Redox Complex***, are presented in Fig. 9. They show the spatial correspondence of maximum (greater than 1.5 times the background level) of the magnetic susceptibility with minimum (between -20 and -5 mV) of the Redox Potential and correlated with increases of vanadium (V) and nickel (Ni) (between 2 and greater than 3 times the background level), both for the southern block and for the north (only one station). Such spatial correspondence establishes the existence of a preserved occurrence of light hydrocarbons in the order of depth of 1600m.

5. Conclusions

The results of the investigations with non-seismic and non-conventional methods in the study region indicate that the non-seismic anomalous complex of the Cristales oilfield is reproduced in the locality of La Vigía. The possible occurrence has an areal extension between 5-15 km^2, with a

probable depth close to 1000 m or less and is associated with a presumably feeder fault to the north and parallel to the Cristales fault. The target manifests itself as a possible preserved occurrence, by virtue of the results of the recognition works by the ***Redox Complex***.

The 2D modeling of potential fields in the Jatibonico oilfield validated the hypothesis that the regional magnetic RP maximums, greater than -75 nT, are a cartographic expression of continental margin carbonate uplifts.

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J. Morales González, es Ing. Geofísico de 2016, obteniendo el Premio de Mérito Científico. Se desempeña como profesor Instructor de la Universidad Tecnológica de La Habana "José Antonio Echeverría", Cuba, de la carrera de Ingeniería Geofísica, en la cual ha impartido asignaturas como: teoría del potencial, métodos de prospección gravimétrica, procesamiento de datos en las geociencias, métodos radiométricos y geofísica nuclear, y métodos geofísicos aplicados a la prospección exploración y explotación de yacimientos de hidrocarburos. Durante sus años de graduada ha cursado postgrados como: prospección sísmica, magnetometría, gravimetría, procesamiento de datos, petrofísica, geología regional, introducción a sedimentación carbonatada y estratigrafía secuencial sísmica en carbonatos (Curso de la Repsol). Geología estructural: estilos estructurales (Curso de la Repsol). geoquímica y análisis/modelado de cuencas (Curso de la Repsol), economía de proyectos y contratos petroleros. En la actualidad trabaja en el desarrollo de su investigación doctoral en opción al grado de Doctor en Ciencias Geológicas titulado: Caracterización geólogo-estructural y perspectividad gasopetrolífera de la Cuenca Central, Cuba, a partir de datos geofísicos.
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O. Rodríguez Morán, es Ing. Geofísico de 1980. Ocupa el cargo de Investigador I. Es MSc. en Geología Petrolera y Dr. en Ciencias Técnicas, además es profesor de la Universidad Tecnológica de La Habana "José Antonio Echeverría", Cuba, de la carrera de Ingeniería Geofísica. Ostenta la categoría de Investigador Titular. Posee más de 34 años de experiencia en temas como el procesamiento de datos en la geociencias, modelación matemática para el pronóstico de yacimientos de hidrocarburos, interpretación geofísica, análisis de riesgo en la exploración petrolera, pronóstico con técnicas de reconocimiento de patrones, modelación matemática, diseño de bases de datos en plataforma Microsoft Access y programación en Visual Basic. También, se posee experiencia en la impartición de asignaturas como: metodología de la investigación científica y procesamiento de datos en la geociencia. En la actualidad trabaja en el desarrollo y aplicación del Complejo Redox, que es un método geofísico-geoquímico no convencional de exploración de yacimientos hidrocarburo.
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